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Aircraft Alerting Systems Standardization Study, Phase IV, Accident Implications on Systems Design

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Final Report

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16. Abstract

This study, the fourth in a series having evolved from a study of independent altitude monitor requirements and alerting system criteria, has developed a set of substantiated guidelines for the design of aircraft alerting systems.

In the course of this work, the FAA concluded that a system which went beyond the function of an alerting system might be useful. The study was extended to examine the question as to whether a system could function as a monitor of flight safety, a system that could aid the pilots in resolving problems and contribute to reducing the number of future accidents.

The study established the feasibility of the concept of complementing the alerting system with a computer to perform the flight phase status monitor function.

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METRIC CONVERSION FACTORS

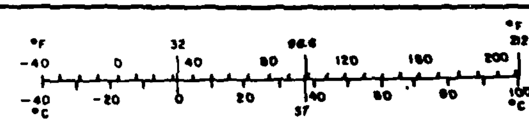
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This report covers work performed under FAA Contract DOT-FA79WA-4268, "Aircraft Alerting Systems Standardization Study." This phase of the study entitled, "Accident Implications on System Design," was initiated to evaluate the feasibility and benefits of additional computation and processing for alerting functions. Earlier phases of the study produced a set of guidelines for the design of alerting system displays for future commercial transport aircraft. The present effort addresses the question whether the alerting system could function as a monitor of flight safety, to aid the pilots in resolving problems and reduce future accidents/ incidents.

The contract sponsor was the FAA Systems Research and Development Service (SRDS). The study was conducted as a joint effort of three major U.S. manufacturers of commercial transport aircraft: Boeing, Lockheed, and McDonnell Douglas. The program manager for the study was Mr. Wayne D. Smith of the Boeing Commercial Airplane Company. The program manager for Lockheed efforts was Mr. M. F. Leffler. Dr. R. F. Gabriel was the program manager for Douglas Aircraft. Technical support was provided by R. C. Cokeley and R. P. Smerke of Lockheed and J. B. Erickson of Douglas Aircraft. Technical guidance for the contract was provided by Mr. John Hendrickson, ARD-340, the contract monitor.

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LIST OF ABBREVIATIONS

ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
CAB	Civil Aeronautics Board
CRT	Cathode Ray Tube
DETAC	Digital Equipment Techology Analysis Center
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
GPWS	Ground Proximity Warning System
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
MEL	Minimum Equipment List
NASA	National Aeronautics and Space Administration
NTSB	National Transportation Safety Board
RAM	Random Access Memory
TCV	Terminal Configured Vehicle
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VOR	VHF Omnidirectional Range

1.0 INTRODUCTION

1.1 PROGRAM HISTORY

This study of aircraft alerting systems and ad· ·nced flight status monitor concepts was initiated in 1973 when the Federal Aviation Administration (FAA) contracted Boeing to study concepts for independent altitude monitors. One of the goals of this effort was to identify a unique alerting method for an independent altitude monitior (Ref. 1). A follow-up study, conducted in 1974-1975, investigated operational philosophies for implementing effective and reliable alerting systems. The study provided a summary of alert philosophies and alerting characteristics used in then-current aircraft (Ref. 2). In 1976 the FAA extended the study to investigate alerting methods used in the design of commercial transports. The results of that study provided basic concepts for design objectives and guidelines for alerting systems for future aircraft (Ref. 3). Table 1-1 shows the objectives of this, and the earlier studies.

The major findings of the 1976 study were as follows:

- There had been a significant increase in the number of alerting signals used on new commercial transports. For example, in going from the 707 to the 747, the number of alerting signals increased from 188 to 455, or 142 percent. The increase from the DC-8 to the DC-10 was from 172 to 418, or 143 percent.

- Very little standardization had been used by the airframe manufacturers in implementing alerting system elements. Not only were there vast differences between airframe manufacturers, but individual manufacturers were inconsistent in the application of alerting signals within their airplanes.

Table 1-1. Previous Alerting System Studies—Contract DOT-FA73WA-3233

Title (Report =)	Development of an independent altitude monitor concept (FAA-RD-73-168)	Independent altitude monitor alert methods and modes study (FAA-RD-75-86)	Collation and analysis of aircraft alerting systems data (FAA-RD-76-222)
Objectives	• Identify nature of typical inadvertent terrain impact accident scenarios • Identify techniques whereby inadvertent terrain impact accidents might be reduced • Identify functional elements of an independent altitude monitor concept • Identify methods of implementing independent monitor systems	• Develop operational alert philosophy and concepts • Demonstrate and refine selected independent altitude monitor alerting methods • Develop independent altitude monitor implementation plan	• Tabulate current alerting methods and requirements for all cockpit alerting functions • Develop method for prioritizing alerting functions • Prioritize alerting functions • Correlate requirements with prioritized functions and note conflicts • Broaden stimuli response data base • Define tests for acquiring stimuli response data not available in literature but required for designing alerting systems • Provide recommendations for standardization of alerting functions and methods
Period	February 1973 to September 1973	June 1974 to July 1975	January 1976 to May 1977

For these two reasons, proliferation of alerts and the lack of standardization, airline pilots were beginning to view alerting systems as a nuisance rather than a help. It was reported in 1977 that "Caution and warning systems were originally installed as a reasonable means of assisting pilots to maintain safe, reliable, and economical system operation in the face of high workloads. However, these systems, intended to reduce hazards, are themselves becoming hazards. The vast increase in the numbers of alerts and the frequent occurrence of false or nuisance alerts impose heavy demands on the aircrew. More alerts require more memorization, higher workloads and could induce a higher probability of error" (Ref. 4).

The identification of these problems in current day alerting systems led to the present study, conducted under contract DOT-FA79WA-4268. Table 1-2 summarizes the major objectives of the present study contract, the goal of which is to develop design guidelines for improving and standardizing future aircraft alerting systems. To promote this standardization, the work was performed as a joint effort between the three major U.S. commercial aircraft manufacturing companies with Boeing as prime contractor and Lockheed and Douglas Aircraft as subcontractors.

1.2 PRESENT STUDY

During the course of the present study, interest was developed within the FAA in expanding the requirements of the alerting system defined in the previous studies to include flight monitoring. Past efforts had been concerned with those system functions and components which are directly involved in alerting the aircrew of abnormal conditions or situations. The focus was on how to best display a given alert, given its urgency level. Several assumptions were made in developing the alerting system guidelines:

- An event had occurred
- A fault had been identified
- The urgency of the alert had been established
- The flight crew has to be alerted.

Table 1-2. Aircraft Alerting Systems Standardization Study—Contract DOT-FA79WA-4268

TITLE (Report #)	**Phase I** Define prototype alerting system concepts (FAA-RD-80-68)	**Phase II** Plan tests for prototype alerting system concept evaluations	**Phase III** Evaluate prototype alerting system concepts (FAA-RD-81-38 I & II)
OBJECTIVES	• Acquire missing stimuli response data via appropriate simulator tests • Define alerting system concepts • Assess physical characteristics of each concept • Assess implementation feasibility of each concept • Select alerting system concepts for comparative evaluation	• Select simulation facility • Develop test plan • Coordinate test plan with FAA	• Develop brassboard hardware for selected alerting system concepts • Perform comparative simulator evaluation of selected concepts • Finalize design guidelines for standardized alerting system • Assess certification impact

The Aircraft Alerting Systems Design Guidelines developed in Phase III of this study, (Ref. 5) will foster uniformity in alert presentation among different aircraft types. However, much more than alerting systems components (e.g., tones, master warning and caution lights, voice messages, etc.) will be required to perform the flight status monitor function. The primary differences between an alerting system and a flight status monitor system are:

- A flight status monitor system could alert the crew to operational as well as mechanical abnormal conditions, and could also inform the crew of the proper corrective action.
- A flight status monitor system would be computer-based and be programmed to prioritize and/or inhibit alerts during critical flight phases and during multiple failure conditions.
- Being computer-based and linked to other cockpit systems, the flight status monitor could provide crew alerting for a wider range of functions, including flight operations.
- Being computer-based, the flight status monitor could use stored information acquired from maintenance experts and sensor data to perform trend analysis and provide the crew with indications of system degradation and failure prior to detection by primary alert sensors.

To transform an alerting system into a flight status monitor, the following component functions are needed:

- sensing to provide source information;
- interfacing to other aircraft systems for data transfer;
- computing and processing to assimilate and process status informa-

tion using predefined algorithms and to decide what alerts need to be displayed and when;

- o displaying checklists and other data to aid the crew in responding to abnormal conditions;

- o providing controls to enable the crew to interact with the expanded system.

The alerting system defined in Phase III of the present contract would only provide the alerting function of a flight status monitor system. A Phase IV effort was therefore initiated to assess the feasibility of and to identify some of the functional requirements for a flight status monitor system.

This study, entitled "Accident Implications on System Design," was conducted as three related tasks:

1. Examination and analysis of aircraft accident and incident data to identify the factors that have contributed to aircraft accidents or incidents;

2. Examination of the cockpit environment;

3. Development of expanded concepts for alerting systems to monitor flight status and enhance crew response to abnormal conditions.

This report desribes the activities that were conducted to accomplish these three tasks and summarizes the major findings.

While the study assesses the role of the alerting system in monitoring aircraft system status and operational activities, it has not considered the alerting system as a piece of hardware. As with design guidelines recently published, only the functional requirements for a flight status monitor were considered. Sensors were considered as a sensing function, and computers and processors were considered only for their computational function. Distributed versus centralized computer designs were discussed but not made a part of recommended functional requirements.

1.3 REPORT ORGANIZATION

Section 2 of this report is an Executive Summary of the major activities and findings of the Phase IV effort. The objectives, procedures and results of Tasks One and Two are contained in Sections 3 and 4, respectively. Conclusions and their implications on the concept of a flight status monitor system are contained in Sections 5 and 6. Section 7 describes additional functional requirements for the design of a flight status monitor system. Considerations for implementation of such a system are contained in Section 8. Recommended future activities, including a flight test program are described in Section 9. The forms used to collect data for Tasks One and Two are contained in the Appendices.

2.0 EXECUTIVE SUMMARY

2.1 PROGRAM BACKGROUND

This study, the fourth in a series having evolved from a study of independent altitude monitor requirements and alerting system criteria, has developed a set of guidelines for the design of aircraft alerting systems.

During the conduct of the study, questions were raised as to how an alerting system could further aid the crew besides simply displaying alerts for system failures that occur. Recent aircraft accidents raised questions as to whether the aircraft alerting system could function as a monitor of flight safety, i.e., a system that could aid the crew in resolving problems and perhaps reduce future accidents. Figure 2-1 depicts the flight status monitor concept.

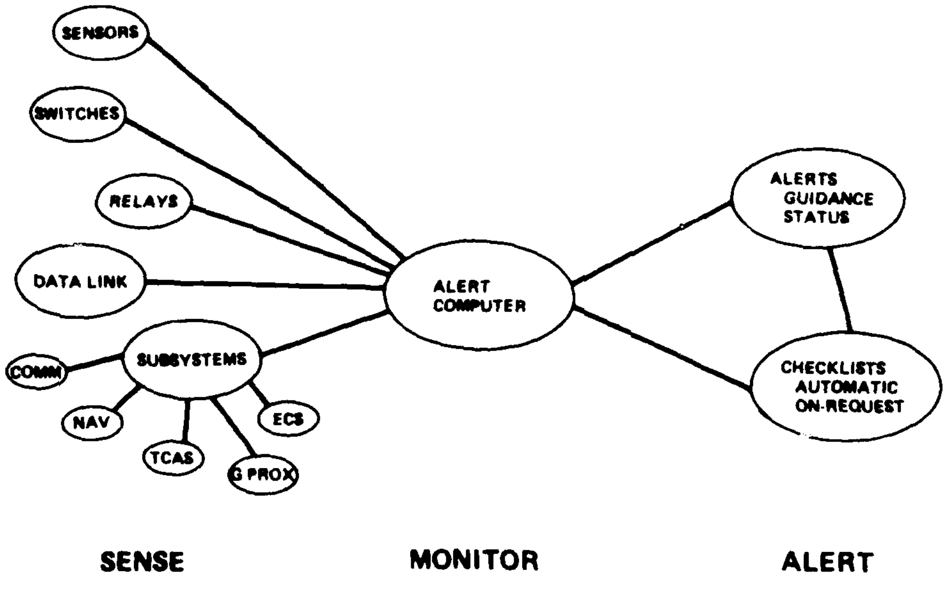

Figure 2-1. Flight Status Monitor Concept

These questions led to the extension of the alerting system study contract to include Phase IV, which was titled, "Accident Implications on System Design."

2.2 CURRENT PROGRAM

Phase IV consisted of three related tasks: analysis of aircraft accident and incident data, examination of the cockpit environment, and, based on the results of the first two, development of expanded alerting system design concepts.

2.2.1 TASK ONE—EXAMINATION AND ANALYSIS OF AIRCRAFT ACCIDENT AND INCIDENT DATA

2.2.1.1 OBJECTIVES AND PROCEDURES

This task consisted of examining and analyzing data from recent aircraft accidents and incidents. An objective of the review was to determine whether any dominant cause(s) existed in the accidents and incidents, and to establish relationships between the causal factors and the alerting system. The ultimate objective was to provide relevant situations or failures for analysis in the development of concepts in Task Three.

Under Task One, the study team reviewed National Transportation Safety Board (NTSB) reports of U. S. air carrier accidents, reports from the Aviation Safety Reporting System (ASRS), foreign government reports, International Civil Aviation Organization (ICAO) reports, and company in-house sources.

Two data bases were developed. A total of 160 accidents and incidents from sources other than ASRS were reviewed. A total of 163 ASRS reports were reviewed, but because of the significant differences between the data recorded in the ASRS reports and the NTSB-type reports, the data were kept separate. One data base was formed from the ASRS data, and the other came from the NTSB-type reports. For the remainder of this report the term NTSB will refer to all data sources except the ASRS.

2.2.2 TASK TWO—EXAMINATION OF THE COCKPIT ENVIRONMENT

2.2.2.1 OBJECTIVES AND PROCEDURES

This task consisted of examining the cockpit environment by riding on commercial transport flights to observe flight deck operations, procedures, and crew member activities. An objective of this task was to evaluate the operational environment (the flight deck) in which the emergencies occur. The investigation included the observation of:

- frequency of occurrence of alerts
- crew member response(s) to alerts
- alerting system operation
- flight deck operations and activity
- crew member responsibilities and activity
- crew member survey of alerting system needs.

A total of 52 flights were flown. A diversity of experience was obtained, including day/night flights of long/short duration in various types of aircraft operated by various airlines.

2.3 CONCLUSIONS FROM TASKS ONE AND TWO

2.3.1 EXAMINATION OF ACCIDENT DATA (TASK ONE)

2.3.1.1 NTSB DATA BASE LIMITATIONS

The NTSB accident histories reviewed in the study included a high proportion of crew-caused accidents. For the purposes of the study it was desired to review a large number of crew-caused accidents. Previous studies have shown that a majority of hull-loss accidents are determined to be caused by crew error (Ref. 6). Therefore, of the 160 accidents/incidents examined, 99 were hull-loss accidents, 20 resulted in substantial damage, 27 resulted in minor damage, and only 14 resulted in no damage to the aircraft.

The data from the present accident review also showed a correlation between loss of aircraft and crew causal factor. Of the 43 accidents for which only one cause was apparent, twenty-one were labeled as crew error. It was noteworthy that every crew-caused accident was a hull-loss accident. Equally important, however, is that when the flight crew is lost with the aircraft, little data is available to evaluate the performance of the crew or the alerting system.

2.3.1.2 ASRS DATA BASE LIMITATIONS

ASRS reports are submitted voluntarily by participants in the aviation community. After preliminary processing, all ASRS reports are written so that there is no way to identify individuals submitting or named in the reports. ASRS reports tend to be sketchy by nature, however, further "sanitizing" of the reports can be practiced. It is suggested that additional data such as airplane model and dates should be made available to legitimate research efforts. A more detailed submittal form requirement and a more detailed follow-up (CALL BACK) would enhance the system.

2.3.1.3 CRITICAL FLIGHT PHASES

The data have shown that certain phases of flight produced more accidents than others. Sixty percent of the accidents occured in three of the nine phases of flight defined for the study. Takeoff produced 21 percent of the accidents, while final approach contributed 23 percent and landing contributed 16 percent.

During takeoff, final approach, and landing the flight crew is exposed to the hazard of an inadvertent collision with the ground. In these flight phases, the flight crew experiences the greatest workload, activity, and opportunity for irreversible errors. Crew error was found to be the principal cause for accidents in the final approach and landing phases, and, although mechanical failures were more numerous than crew errors in accidents during takeoff, the flight crew is responsible for safe recovery from those mechanical failures.

2.3.1.4 MULTIPLE FACTOR ACCIDENTS

The data indicates that most of the accidents were not the results of a single failure, deviation, mistake, or misjudgment; they were the result of accumulating or compound problems. They were shown to be the result of combinations of causes, primary and contributing.

Over 73 percent of the accidents examined indicated multiple causes for the accidents. Since only 21 of the accidents were the result of a single cockpit crew error, it is apparent that the majority of crew errors were committed in conjunction with other factors, including other crew factors. Many of the crew errors were the result of improper responses to situations precipitated by other causal factors. In such cases, instead of the crew providing a recovery from the situation, they often aggravated it.

2.3.1.5 ANALYSIS OF CREW ERRORS

Considering both primary and contributing causal factors for all accidents, crew errors outnumbered mechanical failures by 177 to 87, or over 2 to 1. When only the hull-loss accidents which generally occurred during the critical flight phases were considered, errors attributed to the crew outnumbered mechanical failures by 132 to 14 or 5.5 to 1. This difference supports the suggestion that high crew activity and increased workload situations may provide an environment conducive to crew errors.

Air carrier accidents are extremely complex events; over 73 percent of the accidents examined reported multiple causes for the accident. The data showed that when alerting devices were reported to have been activated, accidents reported to be caused by crew error had over twice as many devices activated, on the average, than when the primary cause was mechanical failure. It suggests that the crews may respond without error when only a few alerting devices were going off, but may make errors when many alerts go off. Several situations can cause a large number of simultaneous device activations:

- o Multiple failures

- o Major component failure--coupled sub-components cease to function

- o Failures annunciated by many devices.

Compounded failures or a confusing barrage of horns, lights, and bells can create the high activity and stressful environment which fosters incorrect responses and failure to follow correct procedures.

When crew error was the primary cause (sample of 21), the most frequently reported errors were:

- Misjudged speed, distance, altitude, clearance, etc. (29%)

- Navigation (19%)

- Failed to follow approved procedures (14%).

Table 2-1 lists the predominant detailed causal factors for each major causal factor extracted from the 160 accidents in the data base.

Table 2-1. Predominant Detailed Causal Factors for Each Major Causal Factor

Major causal factor	Predominant detailed causal factor
Crew error	• Failed to follow approved procedures, directives, instructions, etc. (21%) • Misjudged speed, distance, altitude, clearance, etc. (14%) • Selected wrong action or took no action when one was required (11%) • Inadequate supervision by the pilot in command (8%) • Improper application of controls, brakes, flaps, etc. (7%) • Navigation error (6%) • Instruction (person-to-person) misunderstood, ambiguous, or not received (6%)
Weather	• Wind (35%) • Rain and moisture (19%) • Thunderstorms or tornado (19%)
Mechanical	• Fire, flame, smoke, or explosion (16%) • Corrosion, embrittlement, fatigue (16%) • Tire failure or wheel failure (14%) • Power plant (cowling, electrical harness, ducts, etc.) (11%)
Operational	• Aborted takeoff (29%) • Ran off runway (29%) • Taxi (29%)
Other	• Collision (aircraft, bird, or other object) (33%) • Communications with ATC or company (25%) • Evasive action to avoid collision (17%) • Uncontrolled altitude or altitude deviations (17%)

2.3.2 EXAMINATION OF THE COCKPIT ENVIRONMENT (TASK TWO)

Although the results from the cockpit observation flights were not supported by large statistical bases, they provided supporting data for the accident data analyses. Data was gathered in flights aboard 727, 737, DC-10, and L1011 aircraft.

Major observations include:

- Unwanted Alerts During Critical Flight Phases - A problem with current caution and warning systems was found to be that of alerts presented to the crew when they were not wanted. Pilots commented on getting low-urgency alerts during certain critical flight phases and getting alerts for situations which pose no threat.

- Low incidence of Alerts - Discounting the nuisance alerts, there were no alerts observed in the 52 flights.

- Scattered Alert Indications - The crew commented on the fact that there were so many bells, whistles, and tones in the cockpit, that it takes a few seconds to determine what sound was activated and what system is associated with that sound. They stated that, upon receipt off an alert, the relevant alert indicator must first be located and the alert message understood before action could be taken. This problem is most prevalent in older fleet cockpit layouts which do not have centralized annunciator panels.

2.4 IMPACT OF CONCLUSIONS OF ALERTING SYSTEM DESIGN

Task Three analyses, based on the conclusions of Tasks One and Two, showed that a flight status monitor system should incorporate the following capabilities:

- Flight Phase Adaptation - The system should have the capability to selectively modify priorities and inhibit logic as a function of flight phase.

- Multiple Causes - The system should have the capability to prioritize alerts in the event that multiple alerts occur and to integrate alerting information to facilitiate crew response.

- Checklist Capability - The system should have the capability to provide the crew with the proper corrective action(s) and feedback on the results of their responses.

- Additional alerts - The system should have the capability to present the following alerts as well as other system or operational alerts.

  - Navigation error

  - Tire or Wheel Failure

  - Collision avoidance

  - Aborted takeoff

  - Wind shear.

These alerts were selected using two criteria. First, they were significant in frequency of occurrence or in their potential impact on operational safety. Secondly, the implementation of the alerts requires utilization of digital computer technology (tire or wheel failure excepted).

2.5 REQUIREMENTS FOR FLIGHT MONITORING CAPABILITY

For an alerting system to perform as a monitor of flight status, functional requirements in addition to those inherent in an alerting system must be provided. Besides the requirements for display functions established in the Guidelines (Ref. 5), more extensive information processing and interfacing must be provided. The functional requirements of a flight status monitor include (those in addition to alerting system elements are shown with an asterisk):

- MASTER AURAL ALERT - To alert the crew to impending or existing conditions that require their attention, and to advise them of the alert urgency level.

- MASTER VISUAL ALERT - To attract the attention of the crew and to provide preliminary information about alert urgency level.

- VISUAL INFORMATION DISPLAY - To provide a single location for the presentation of all warning, caution, and advisory messages to the crew.

- VOICE INFORMATION ANNUNCIATOR - To provide voice messages of the alert when the pilot must act rapidly, or to enable the pilots to selectively transfer workload from the visual channel to the auditory channel.

- TIME-CRITICAL DISPLAY - To provide a separate display to enable the pilot to detect and respond to time-critical alerts accurately and rapidly.

- INFORMATION PROCESSING* - To provide the computational and data handling capability including flight phase adaption, multiple alerts, and checklists.

- SENSING* - To provide sources of necessary status information.

- INTERFACING* - To provide for data exchange between the system and other data handling systems such as flight management, performance management, flight control, sensor subsystems, navigation, communications, and maintenance data recordings.

2.6 IMPLEMENTATION CONSIDERATION

In order to provide the additional requirements established for the alerting system, the system must be provided with capabilities in computing and processing, sensing, interfacing, and controlling and displaying.

- Computing and Processing - Algorithms and logic for computation of alert criteria from sensor and memory sources are required; these might be customized for each aircraft and airlines.

- Sensing - Some new sensors may be needed; however, most of the sensors required can already be found on current aircraft.

- Controlling and Displaying - The technology is currently available to implement the flight monitor capability.

- Interfacing - Interfacing will be the same means as other avionics functions on the aircraft: digital data bus in the more sophisticated systems and hard wiring in the more simple systems.

2.7 RECOMMENDED FUTURE ACTIVITY

This phase of the study has established the feasibility of the concept of expanding the functions of the alerting system to perform as a flight status monitor. Since the functional requirements of a flight status monitor sigificantly add to the requirements of the alerting system, it is necessary to take a systems approach to defining the new concept of a flight status monitor.

The concept of the flight status monitor should be refined and demonstrated to be feasible for implementation into hardware for flight deck applications. Following demonstration of feasibility, it is recommended that a flightworthy system be fabricated for evaluation in an operational environment. Finally, it is recommended that the concept system be evaluated in a flight test.

3.0 TASK ONE—EXAMINATION AND ANALYSIS OF ACCIDENT/INCIDENT DATA

Existing data bases were analyzed to identify the factors contributing to the accidents and incidents. The review extracted those situations and failures that created hazardous conditions. Those situations or failures, coupled with data extracted from the Task Two examination of the operational environment, were used in Task Three to develop expanded concepts for alerting systems to provide a flight status monitor capability.

3.1 OBJECTIVES

The primary objective of Task One was to analyze aircraft accident and incident data and identify the major contributing causal factors. The investigation also identified flight crew and alerting system activity in each accident and included the examination of possible interrelationships between causal factors.

Of particular interest were those causal factors which occurred frequently because they represented recurrent or unsolved problems; also of interest were those factors which occurred infrequently but with significant impact. Analyses were performed to identify interdependent relationships, for example, the major causes of accidents/incidents by flight phase (i.e., separate tabulations were made for takeoff, climb, cruise, and landing).

Other questions that were addressed included:

- What problems/failures go undetected and are therefore not announced to the crew?
- What sensors could be developed that would lessen the probability of occurrence or decrease the severity of a problem situation?
- Could the inclusion of new alerts or the reformatting of existing ones help prevent future accidents?

3.2 TECHNICAL APPROACH

The accident/incident data used in this study was taken from several data sources. The data bases were divided among the corporate team members; one member reviewed all ASRS data, while the other two participants reviewed all other sources including company accident/incident data sources. In addition, to simplify identification of causal factors and tabulating results, a computer program was structured to allow statistical analysis of the data. A data partitioning capability was also provided so that analyses could be performed to investigate possible interrelationships between causal factors.

3.3 PROCEDURES

Task One was accomplished by assigning the data bases to be surveyed by each team member. One team member surveyed the ASRS data, provided by the FAA. Each of the other two team members reviewed NTSB and other sources covering accidents/incidents which involved the airplanes manufactured by their company. Each team member was responsible for documenting their survey results. Documentation consisted of entering the information on a standard data collection form.

After the data was collected, a statistical analysis was performed to determine if any dominant cause existed and to support a parametric study of the operational, crew performance, and alerting system performance data.

3.3.1 DATA SOURCES

The sources of data for this survey included reports from ASRS, NTSB, foreign governments, ICAO, and company in-house files. Figure 3-1 indicates the number of times each of the data sources was used as primary or secondary source of information to be entered on the data collection form.

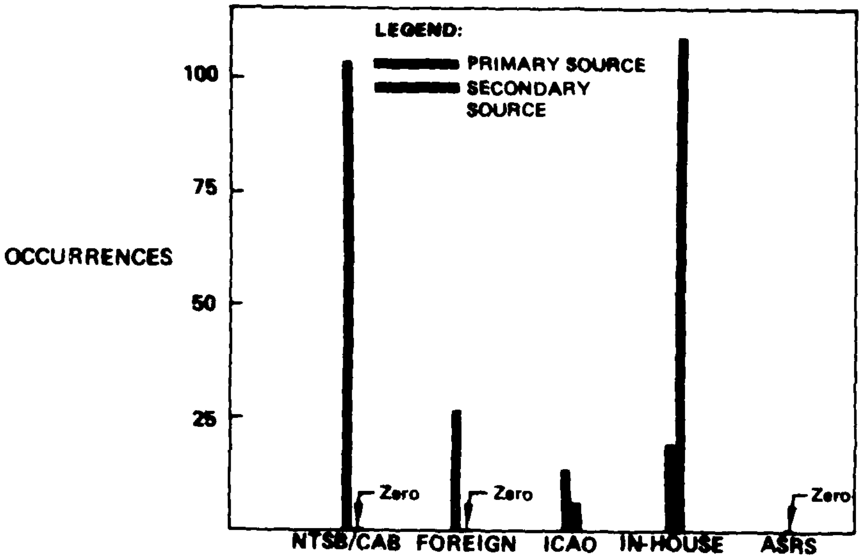

Figure 3-1. Source of Data

As stated earlier, the term NTSB was used to identify all data sources other than ASRS data that were used in this accident data analysis. The NTSB documents were the primary source of information in over 64 percent of the accidents reviewed. Because of the difficulty in correlating accidents reported in the ASRS with NTSB reports, ASRS data collection, analysis, and findings were treated separately. Section 3.4.2 contains the results of the ASRS survey.

ASRS reports in the following seven categories were analyzed. The categories were selected by the contract monitor to provide a large source of crew errors to examine.

- o Altitude Alerting
- o Ground Proximity Warning System (GPWS)
- o False Alarms
- o Checklists
- o Cockpit Displays
- o Aircraft Equipment Malfunctions
- o Alerts and Warnings

On approximately May 1, 1978, significant improvements were instituted in ASRS data processing; this date represents roughly the division between ASRS Data Bases 1 and 2. Table 3-1 lists the categories and numbers of reports received/analyzed. There was insufficient time to analyze all reports received. In general, priority was given to ASRS Data Base 2. A total of 163 ASRS reports were reviewed.

Table 3-1. ASRS Data Sample

	Data base	Reports received	Reports analyzed
Altitude alerting	1 2	84 125	20 40
GPWS	1 2	25 14	– 13
False alarms	1 2	10 10	10 10
Checklists	1 2	22 18	22 18
Cockpit displays	1 2	4 54	– 10+
Equipment malfunctions	1 2	30 61	– 10+
Alerts and warnings	1	16	10+

ASRS reports tend to be sketchy by nature. In addition, significant information is frequently omitted from the reports when they are released. Examples are omission of airplane model, dates, and aircrew position. An early conclusion of this study is that less "sanitized" data should be made available to future research efforts. A more detailed submittal form and a more detailed follow-up requirement would enhance the usefulness of ASRS data. It is possible that more information could have been extracted from the system; however, this was impractical within the time constraints of the present program.

3.3.2 DATA ANALYSIS

The analysis of NTSB data was performed by computer tabulation of the occurrence of each causal factor as entered from the accident data forms. The data was then partitioned so that the causal factors were tabulated by flight phase, activation of alerting devices and cockpit indication of causal factors. Finally, combinations of variables were examined, such as activation of alerting devices and cockpit indication of causal factors. In each case the frequency of occurrence, either independently or in combination with other factors, was the principal analysis objective.

The ASRS data analysis was accomplished by developing a matrix to tabulate the frequency of occurrence of the causal factors as a function of the seven alert categories. This analysis procedure facilitated the determination of trends in the data. Again, frequency of occurrence was used to provide a measure of the significance of the causal factors.

3.3.3 STATISTICAL ANALYSIS

The statistical analysis consisted of computing means and standard deviations for selected parameters and tabulation of individual and combinations of causal factors.

3.4 RESULTS

3.4.1 RESULTS OF THE NTSB SURVEY

The results of the analysis of the NTSB data are presented below.

3.4.1.1 DATA INPUT FORM QUESTIONS

The data input form, designed for this accident history review, contained three basic types of information: reference, system and crew operating, and causal factor. Anticipating some difficulty in finding sufficient data to perform an evaluation of crew and crew alerting system performance, several direct questions were put on the form. The questions were specific so conclusions could be drawn regarding the completeness of the accident summaries. The first question of this nature was, "Were any crew-alerting devices activated?"

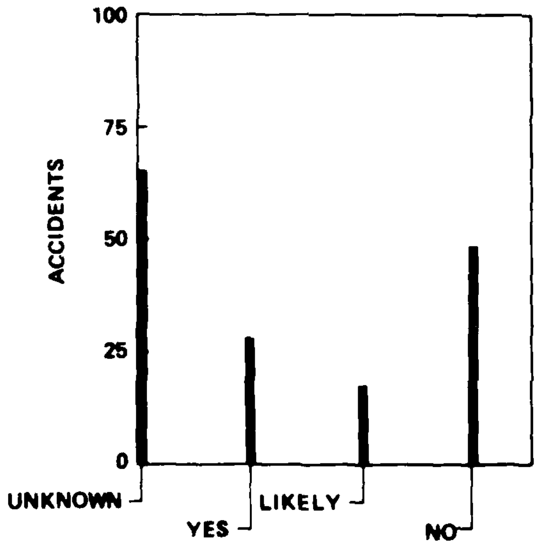

Figure 3-2. Crew-Alerting Devices Activated

Figure 3-2 shows that in 66 (41 percent) of the accidents it was unknown whether any crew alerting devices were activated, according to the accident histories. Further, it is noted that the entry for "NO" (alerting devices activated) may include instances where the report simply did not state that devices were activated. This is most relevant for visual alerts which aren't recorded (aurals are recorded on the cockpit voice recorder). In only 18 percent of the accidents were the analysts able to record that alerting devices were activated at the time of the accident.

Figure 3-3 illustrates what types of alerting devices were reported in the 160 accident/ incident reports. Multiple device activations in an accident are possible. Although it is used for a single fault, the tactile alert for stall warning was reported almost half as many times as visual alerts, which are used for many alerting functions.

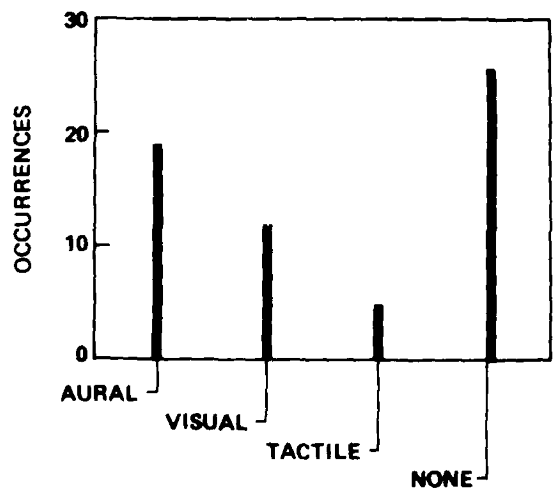

Figure 3-3. Types of Alerting Devices Activated

Figure 3-4 shows the data response to the question, "Were any of the alerts for system failures false alarms?" In the vast majority of cases insufficient data was provided in the data bases to answer this question.

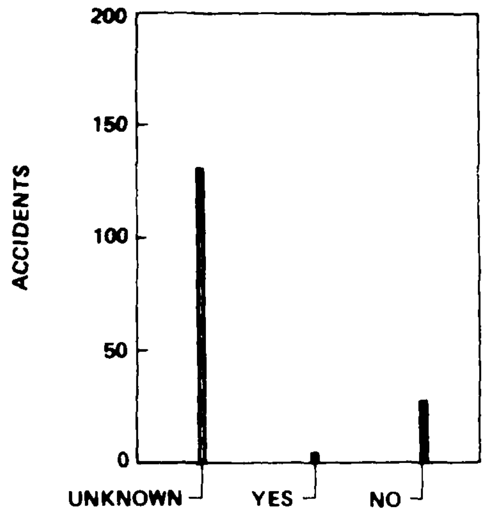

Figure 3-4. False Alarms

Figure 3-5 shows that in only 89 (40 percent) of the reports could it be determined whether the crew had taken the appropriate action for the malfunction. The figure also shows that crew action was inappropriate for the causal factor which caused the accident 39 times and appropriate only 25 times.

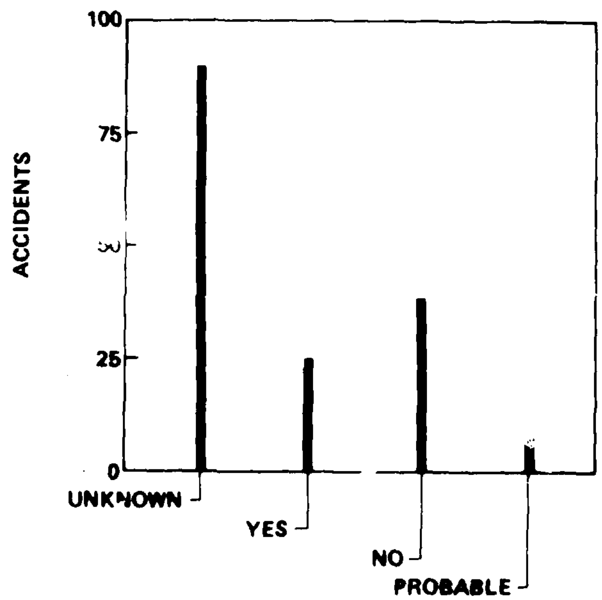

Figure 3-5. Corrective Action Appropriate

Figure 3-6 illustrates the data response to the question of whether the crew was provided with an indication of the causal factors. The fiqure indicates that in 99 (61 percent) of the accidents the analysts were uncertain whether the crews were provided such an indication. The data shows that when the analyst was able to find sufficient information so that a definitive yes/no entry could be made, the crew was not given an indication of the causal factor almost 80 percent of the time.

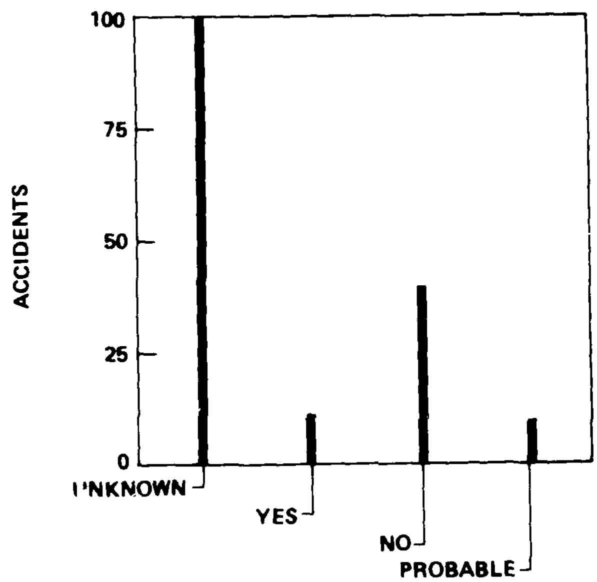

Figure 3-6. Indication of Fault Provided to Crew

The results for, "Who performed the corrective action?" are shown in Figure 3-7. The figure shows that in 120 cases it was unknown, but when it was recorded, the pilot at the controls when the situation occurred performed the corrective action. The data contained no instances when the corrective action was taken by the flight engineer; this draws attention to the fact that the data were derived from accident summaries which documented predominantly catastrophic or serious accidents. The flight engineer would take corrective action normally on only less critical functions.

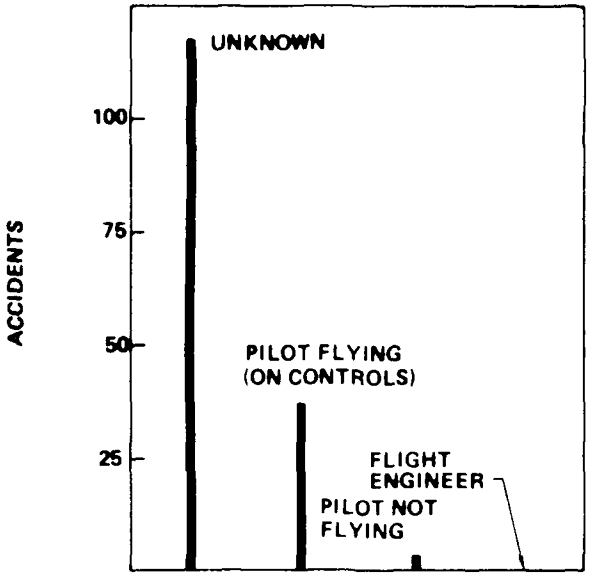

Figure 3-7. Pilot Performing the Corrective Action

Figure 3-8 indicates that the captain was at the controls between 51 and 76 percent of the time when the situation occurred. The use of the term "switched" covers those instances where control of the airplane shifted between the pilots during the handling of the emergency.

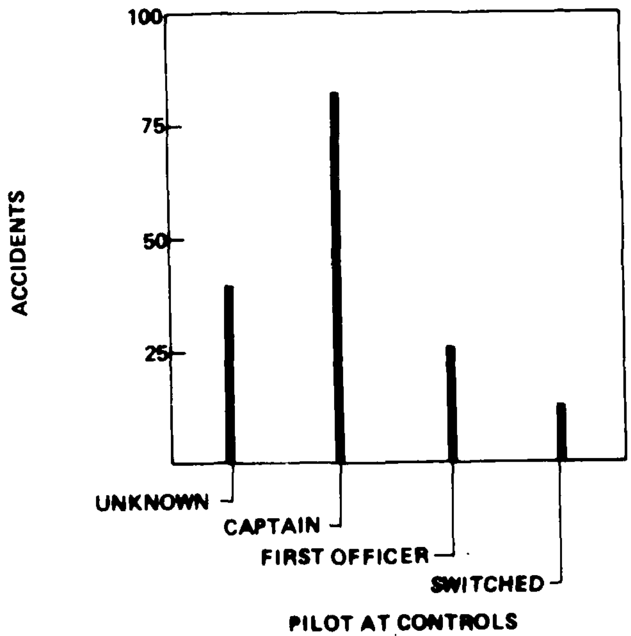

Figure 3-8. Pilot at the Controls at the Time of the Accident

3.4.1.2 MAJOR CAUSAL FACTORS

The data input form used by the analysts, and illustrated in Appendix A, listed two levels of causal factors. The first level was defined as MAJOR, and the second level was defined as DETAILED, so that each major factor included one or more detailed factors. Figure 3-9 shows the frequency of the major causal factors. There were more major causal factors (343) than accidents (160) because the analyst was permitted to log up to five for each accident. Major causal factors were categorized as being either primary or contributing causes for the accident as shown on Page A-4 of Appendix A. The figure illustrates that crew errors were predominant and led mechanical factors by 177 to 87 (includes both primary and contributing causes).

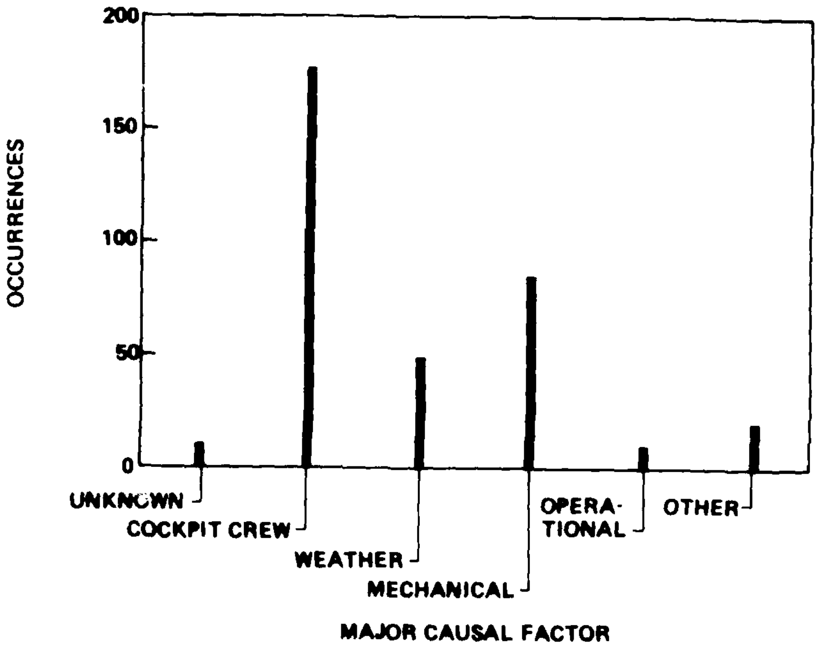

Figure 3-9. Major Causal Factors

3.4.1.3 CAUSAL FACTORS WITHIN MAJOR CATEGORIES

To probe deeper into the major factors which were listed as primary causes for the accidents, the data was partitioned as shown in the next series of figures.

Figure 3-10 shows the detailed causal factors when cockpit crew error was listed as a primary cause (150 times). Pilot failure to follow approved procedures was reported 31 times and pilot misjudgement of speed, distance, altitude, clearance, or other similar parameters was reported 21 times. The identification of the numerically coded causal factors can be found in the data input form in Appendix A, beginning on Page A-5.

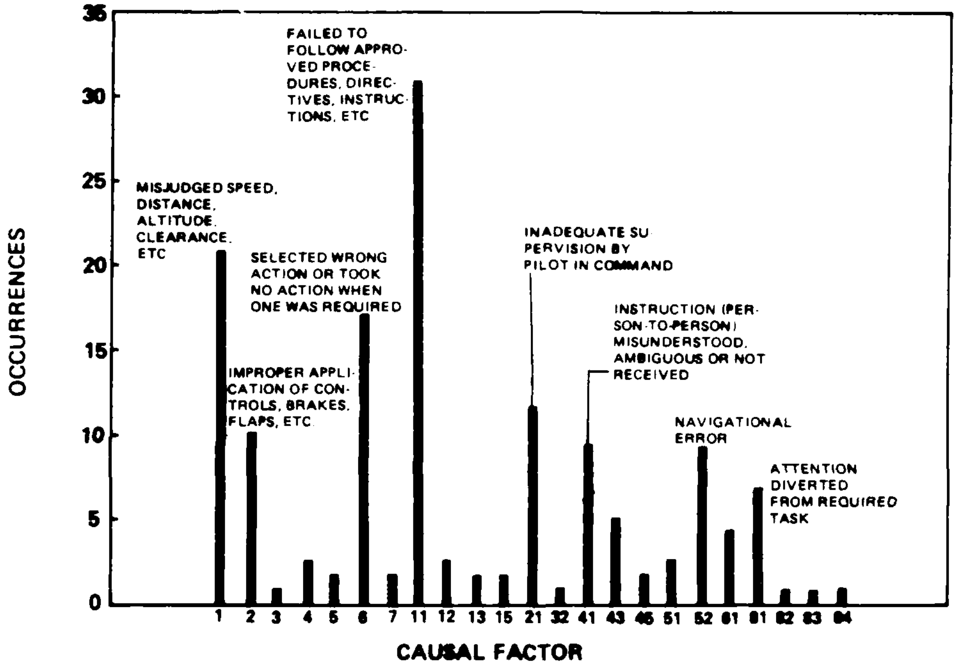

Figure 3-10. Cockpit Crew Error as Primary Causal Factors

Figure 3-11 is a breakout of the detailed causal factors when weather was listed as a primary cause (31 times). Wind, the most frequently recorded factor, includes wind shear.

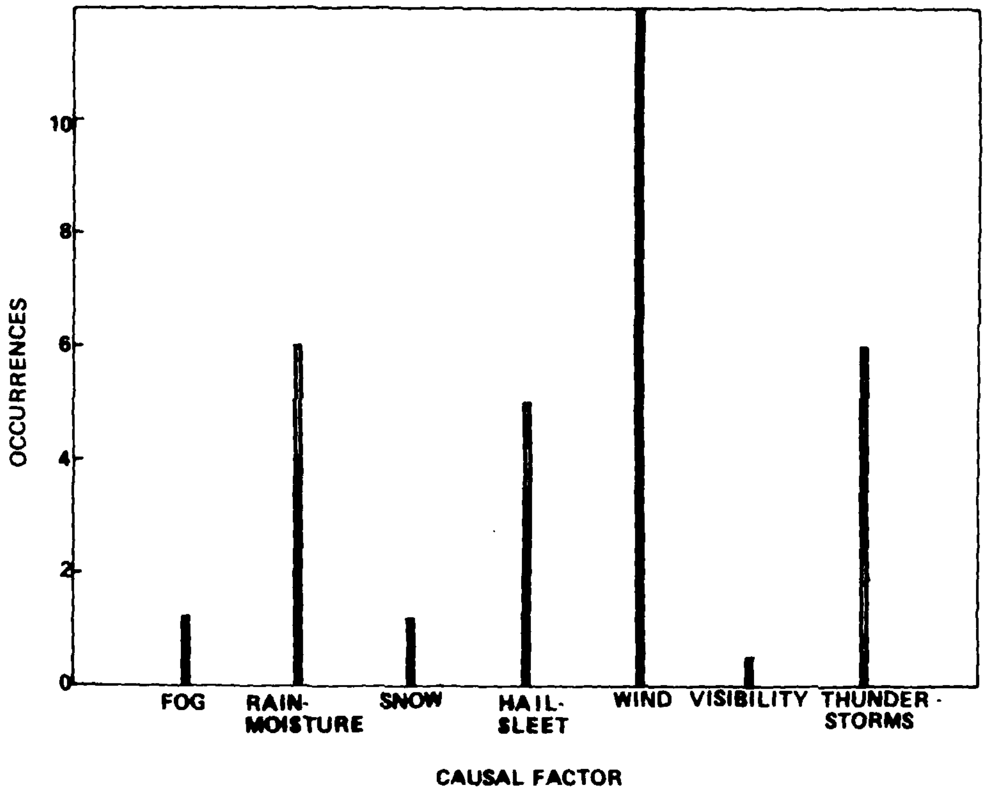

Figure 3-11. Weather Factor as Primary Causal Factors

Figure 3-12 shows the detailed causal factors involved when mechanical factor was listed as a primary cause (64 times).

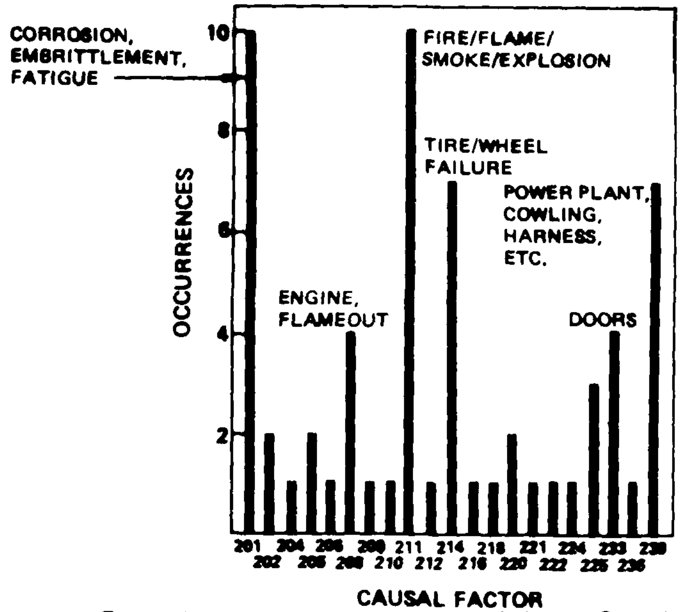

Figure 3-12. Mechanical Factor as Primary Causal Factors

Figure 3-13 shows the detailed causal factors involved when operational factor was listed as a primary cause (7 times).

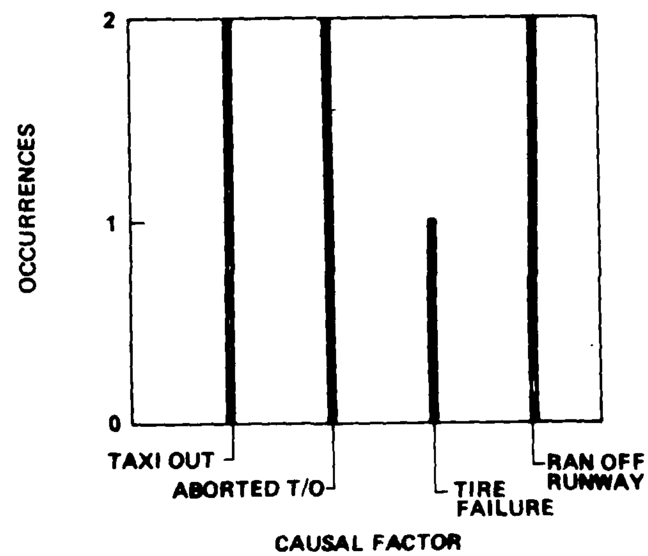

Figure 3-13. Operational Factor as Primary Causal Factors

Figure 3-13

The detailed causal factors involved when OTHER factor was listed as a primary cause (12 sample), are shown in Figure 3-14. This category is comprised of a set of five detailed causal factors as shown in Appendix A. The category contains those causal factors which aren't typical of any particular phase of flight. Experience has shown that this category could be expanded, or integrated with the OPERATIONAL category.

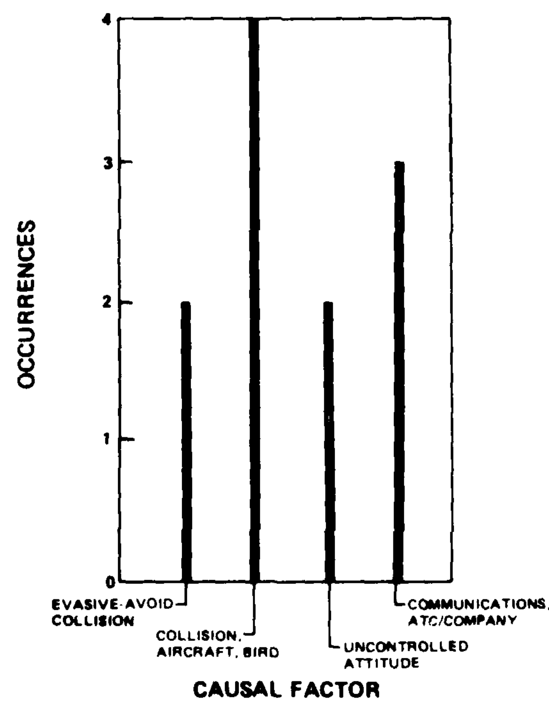

Figure 3-14. Other Factor as Primary Causal Factors

3.4.1.4 ACCIDENT CAUSES BY FLIGHT PHASE

One of the questions which was addressed in this survey of accident histories was what causal factors were prevalent in each of nine flight phases. The flight phases, or flight segments, defined for the task were:

o Takeoff	-	addition of power for takeoff to established in a climb
o Initial climb	-	established in climb to initial flap retraction
o Climb	-	initial flap retraction to level-off at ATC assigned cruise altitude
o Cruise	-	maintaining enroute assigned cruise altitude(s) to descent
o Descent	-	initial descent from cruise altitude to a lower altitude over a navigation/initial approach fix
o Initial approach	-	navigation/initial approach fix to be established on final approach course configured for landing; over outer marker if ILS utilized
o Final approach	-	From out of initial approach or outer marker to flare point
o Landing	-	from flare point through touch-down and landing roll-out
o Taxi	-	maneuvering the aircraft on the ground between landing roll-out and the gate or loading area. Includes subsequent maneuvering from gate or loading area to takeoff point of next flight.

The first cut of the data tabulated the frequency of accidents/incidents in each flight phase. Figure 3-15 shows that 60 percent of the accidents occurred in three flight phases; takeoff, final approach, and landing. Takeoff accounted for 21 percent of the accidents, while final approach contributed 23 percent and landing contributed almost 16 percent.

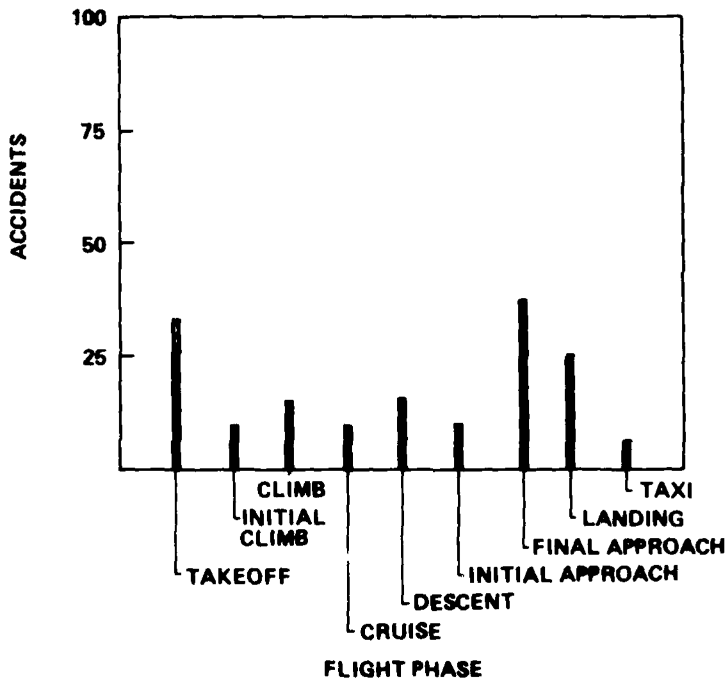

Figure 3-15. Accidents by Flight Phase

After determining in which flight phases accidents and incidents were most likely to occur, something already done in previous safety studies, the data were analyzed for crew errors in each flight phase. The data were partitioned to show the relationship of cockpit crew errors per flight phase and to show what the detailed causal factors were.

3.4.1.5 CAUSAL FACTORS BY FLIGHT PHASE

The cockpit crew detailed causal factors reported to have occurred in each flight phase are presented in this section. Figure 3-16 indicates what crew errors were made in the takeoff phase.

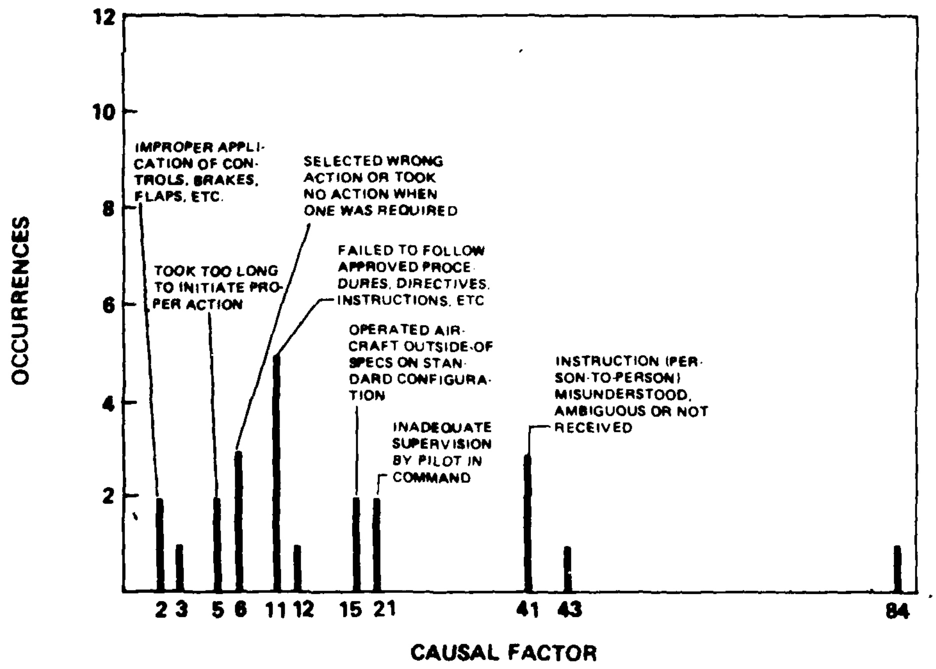

Figure 3-16. Crew Errors—Takeoff

Failure to follow approved procedures contributed 5 of the 23 reported occurrences. There were no pilot errors involving misjudgment of speed, altitude, distance, clearance, etc., in the takeoff phase.

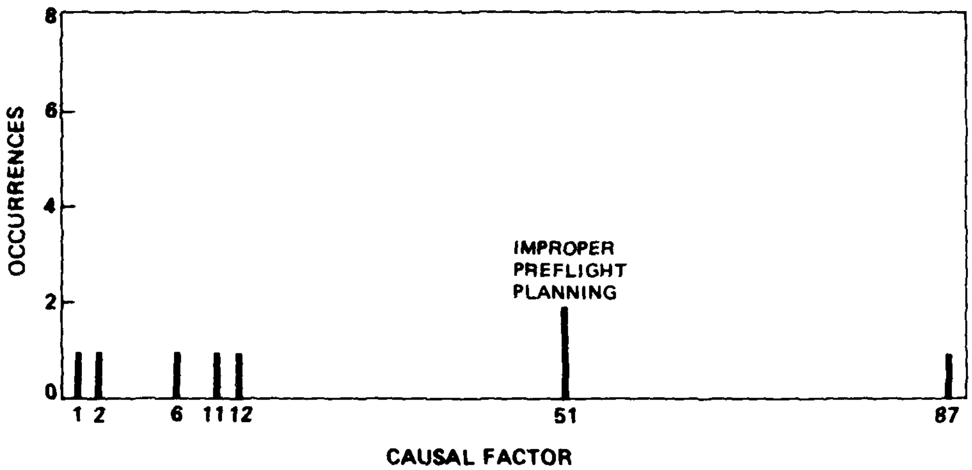

Figure 3-17. Crew Errors—Initial Climb

Figures 3-17 and 3-18 shows the crew errors made during initial climb, and climb.

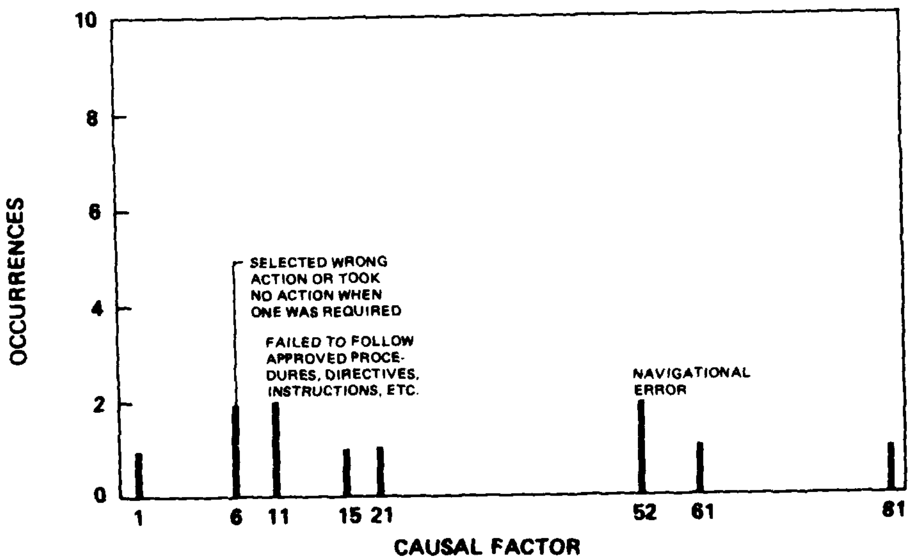

Figure 3-18. Crew Errors—Climb

Figure 3-19 indicates that only 5 crew error causal factors were reported in accidents which occurred during the cruise flight phase. Other safety reports have shown that, although the cruise phase of flight entails 64 percent of the operational time of a typical flight, it contributes only 6.1 percent of the accidents (Ref. 6).

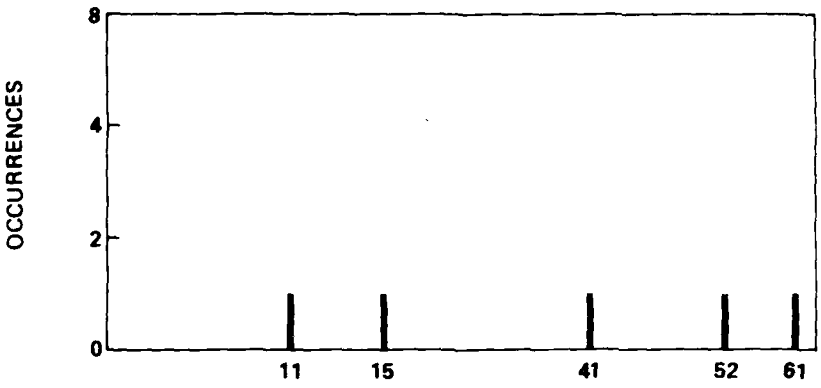

Figure 3-19. Crew Errors—Cruise

Figure 3-20 shows the crew errors made during descent.

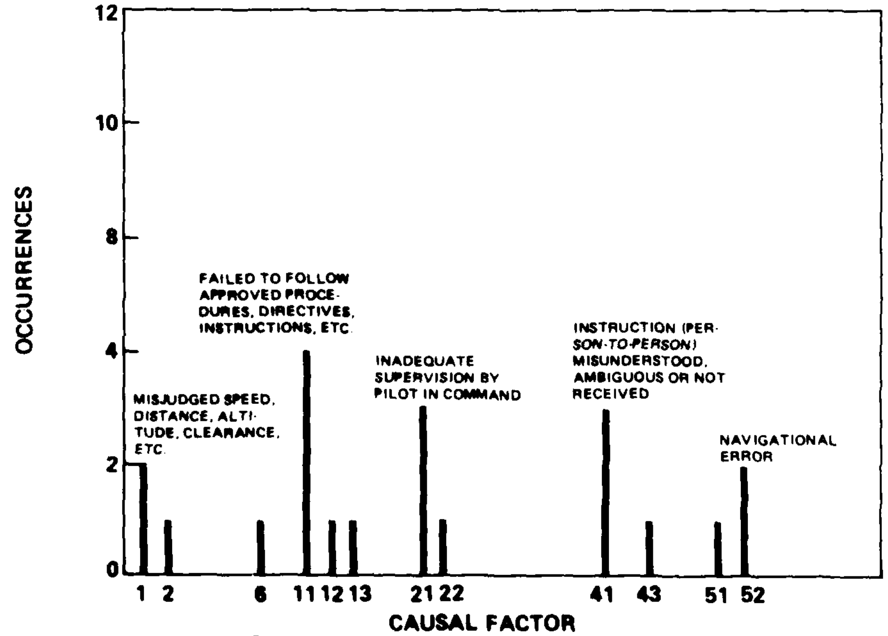

Figure 3-20. Crew Errors—Descent

Figure 3-21 illustrates the errors made by the crew during the initial approach phase. This phase often requires the crew to maneuver the aircraft through an approach to a particular point from which minimum maneuvering to the landing runway is required. Vectors and holding may be involved as well as mountainous terrain. Navigation errors constituted over 29 percent of the errors.

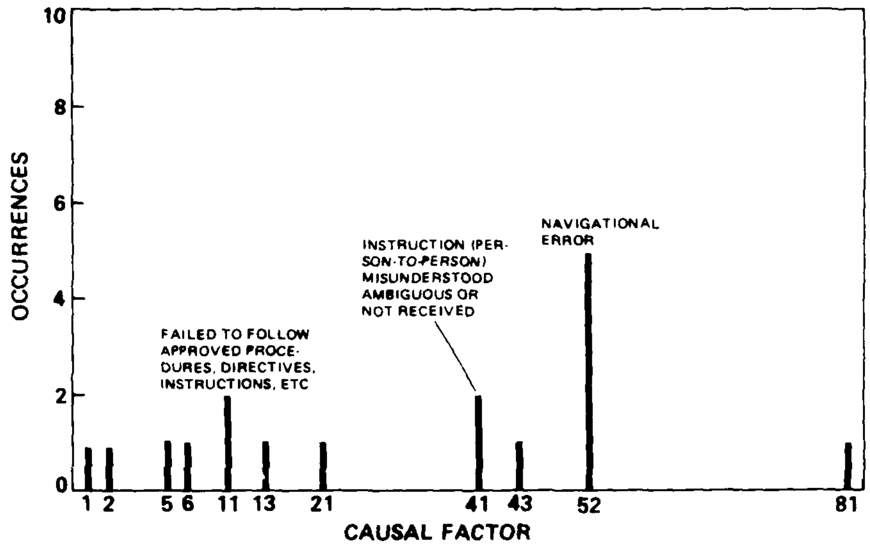

Figure 3-21. Crew Errors—Initial Approach

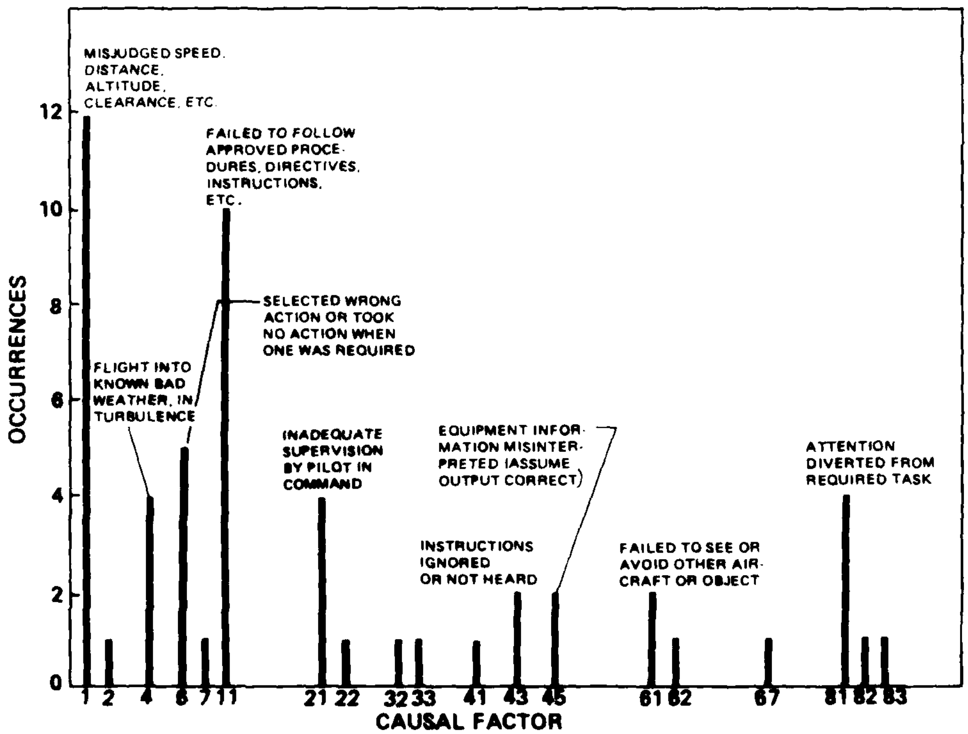

Figure 3-22. Crew Errors—Final Approach

Figure 3-22 illustrates the cockpit crew errors made during final approach. In this phase the crew is occupied with maneuvering the aircraft within strict limitations, preparing the aircraft for landing, and attempting to make/keep visual contact and reference to the ground. Pilot misjudgment of speed, distance, altitude, etc., accounted for 22 percent of these errors, while crew failure to follow approved procedures contributed 18 percent.

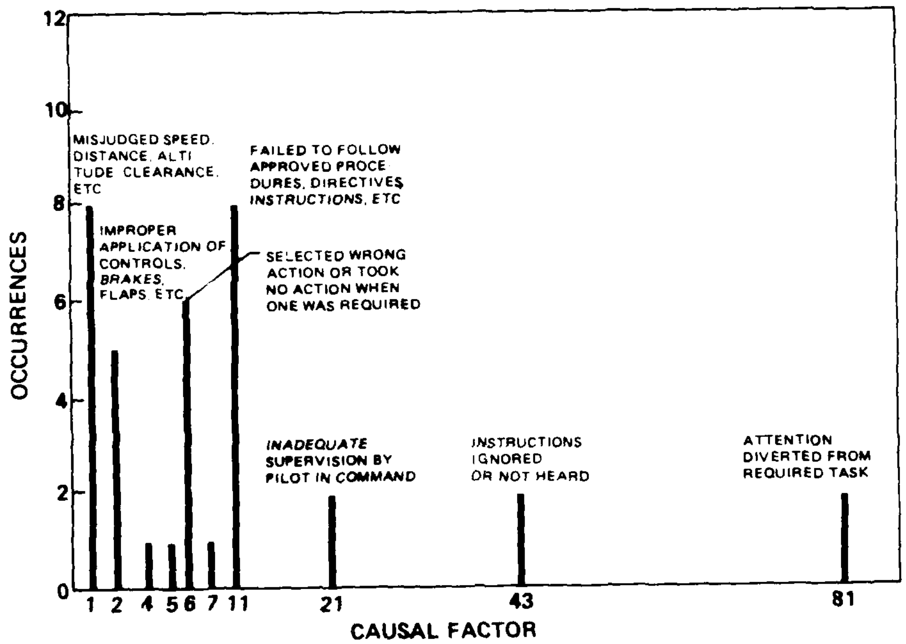

Figure 3-23. Crew Errors—Landing

Figure 3-23 indicates the crew errors which were made during landing. Pilot misjudgment of speed, distance, altitude, clearance, etc., failure to follow approved procedures, and crew selection of wrong action or took no action when one was required accounted for 61 percent of the errors.

Only one crew error was reported during the taxi phase. The error was, "Failed to Follow Approved Procedures". It is noted that, normally, aircraft ground control is separate from approach control and tower control. This requires a change in controllers for taxi instruction and guidance, providing an opportunity for misunderstanding and error.

3.4.1.6 CREW RESPONSE TO ALERTING DEVICES

The appropriateness of the crew response when alerting devices were reportedly activated was investigated. Although the data sample is small, Figure 3-24 shows that even with alerting devices activated, the crew took the wrong action for the situation over 30 percent of the time.

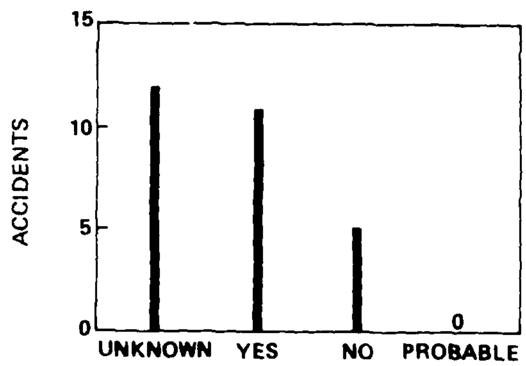

Figure 3-24. Alerting Devices Active—Appropriate Action

3.4.1.7 CAUSAL FACTORS WITH/WITHOUT INDICATIONS

Figure 3-25 shows the causal factors reported when alerting devices were activated and the crew was provided an indication of the cause for the accident.

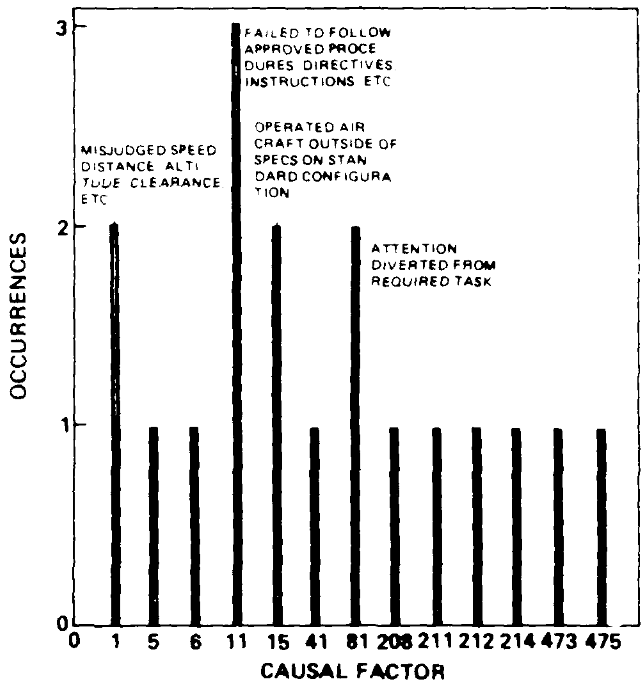

Figure 3-25. Causal Factors With Alerting Devices and Indication of Cause

Under this condition, in the small sample of 18 causal factors, crew errors constituted 67 percent of the causal factors reported.

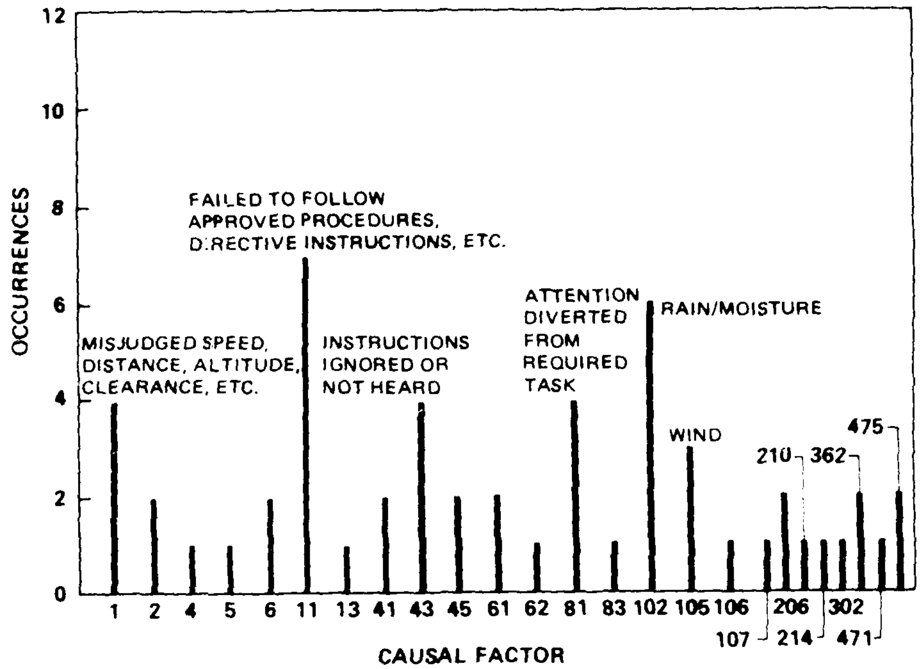

Figure 3-26. Causal Factors Without Alerting Devices and Indication of Cause

Figure 3-26 shows the errors reported when the crew was given no indication of the cause and no alerting devices were reported to have been activated. Under these conditions, crew errors constituted 62 percent. A tabulation of the data in the two figures is shown below:

Major Causal Factor	Occurrences With Alerting	Occurrences Without Alerting
Crew factor	12 (67%)	34 (62%)
Weather	0	11
Mechanical	4	4
Operational	0	3
Other	2	3
	18	55

3.4.1.8 FREQUENCY OF MULTIPLE CAUSAL FACTORS

An accident can be caused by a single factor or a combination of factors. Generally accidents are the result of combinations of causes, primary and contributing. The data base for this accident review contained 160 accidents, 274 primary causal factors, and 79 contributing causal factors. Figure 3-27 shows how many times multiple causes were reported.

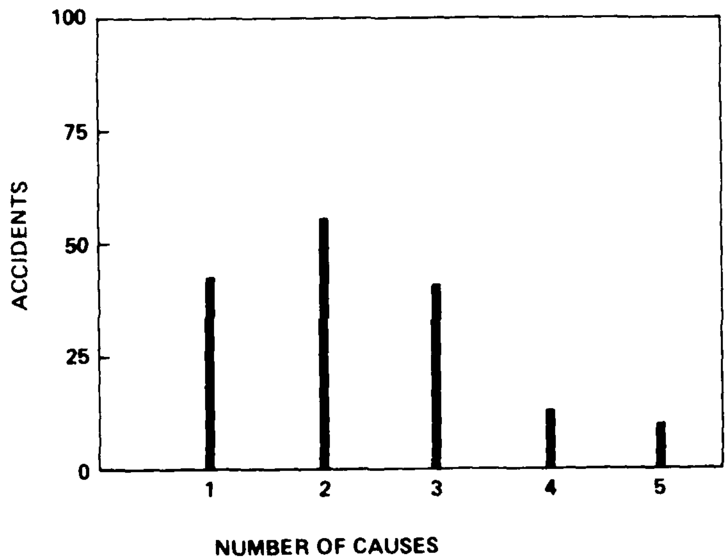

Figure 3-27. Frequency of Multiple Causal Factors

51

The figure shows that 73 percent of the accidents surveyed were the result of multiple causal factors.

3.4.1.9 TYPICAL ACCIDENT PROFILE

Figure 3-28 was developed to format the data to facilitate discussion and analysis. Three phases of flight, takeoff, final approach, and landing were selected, since they produced the most accidents. The totals don't correspond due to unknowns and other variables present. The data can be read as follows:

> The first typical profile is for an accident which occurred during takeoff. This phase contributed 33 of 160 accidents/incidents in the data base. The accident occurred as frequently day or night since 15 occurred in daytime and 15 occurred at night. The captain was at the controls 16 times and the first officer was at the controls 5 times. The weather was VMC, but they were operating under IFR. If visibility was restricted, it was due to fog. The autopilot was not engaged, and the autothrottle was not engaged. The flight had lasted less than 3 minutes. There was one, perhaps two, extra people in the cockpit. An additional note is that the cause for the accident was more likely mechanical over crew factor (32 to 23), and the failure was most likely tire or wheel failure.

- **Takeoff (33-160)**
  - **Equally likely day or night (15-15)**
  - **Captain at the controls (16-5)**
  - **WX VFR (21-7)**
  - **Operating under IFR rules (19-2)**
  - **If visibility is restricted, it is due to fog (8-4)**
  - **Autopilot not engaged (18-0)**
  - **Autothrottle not engaged (19-0)**
  - **Flight lasted under 3 minutes**
  - **Extra person in the cockpit (1.154, σ = 1.214, 13)**
- **Final approach (37-160)**
  - **Most likely daytime (21-14)**
  - **Captain at the controls (18-10)**
  - **WX IFR (22-12)**
  - **Operating under IFR rules (25-7)**
  - **Autopilot not engaged (6-2)**
  - **Autothrottle not engaged (6-0)**
  - **Flight duration 122 minutes**
  - **Extra person in the cockpit (1.615, σ = 0.650, 13)**
- **Landing (25-160)**
  - **Most likely daytime (15-8)**
  - **Captain at the controls (15-3)**
  - **WX IFR (16-8)**
  - **Operating under IFR rules (20-2)**
  - **Autopilot not engaged (6-0)**
  - **Autothrottle not engaged (6-0)**
  - **Flight duration 130 minutes**
  - **No extra people in the cockpit (0.333, σ = 0.500, 13)**

Figure 3-28. Typical Accident Profile

The second paragraph should be read as follows:

> The second typical profile is for an accident which occurred during final approach. The accident most likely occurred in daytime, and the captain was at the controls. The weather was IMC, and they were operating under IFR. The autopilot was not engaged, and the autothrottle was not engaged. The flight had lasted 122 minutes, and there likely were two extra people in the cockpit. An additional note is that the most likely cause for the accident was crew error over mechanical factor (55 to 4), and the most likely cockpit crew error was that the pilot misjudged his speed, altitude, distance to the runway, or some such parameter, or the crew failed to follow established procedures.

The third paragraph should be read as follows:

> The third typical profile depicts an accident during the landing phase. The accident most likely occurred during daytime and, again, the captain was at the controls. The weather was IMC, and they were operating under IFR. The autopilot was not engaged, and the autothrottle was not engaged. The flight had lasted 130 minutes. There were no extra people on the flight deck. An additional note is that the most likely cause for the accident was crew error (36 to 8) and the error most likely was pilot misjudgment of his speed, altitude, or the crew failed to follow established procedure.

3.4.2 RESULTS OF THE ASRS SURVEY

The results of the ASRS survey are presented in this section. Findings from the review of reports in the altitude alert, ground proximity, and false alarm categories are presented.

3.4.2.1 ALTITUDE ALERTS

The ASRS categorized 209 reports of altitude deviation from assigned altitude in the period 7/1/76 to 2/2/80. These are commonly called "altitude busts". Several additional incidents involving altitude alerting were associated with reports in other categories. A summary of the significant details of 63 incidents follows:

63 Reported "Altitude Busts"	Frequency	%
Association with Distraction/Added Workload	36	57%
Crew Cross Check Obviously Lacking	34	54%
Altitude Deviation Alert not Seen/Heard	24	38%
Clearance Misunderstanding	20	32%
Altitude Alert Mis/Not Set (Clearance OK)	7	11%
Pilot Comment - Alert Design (Deficiency)	19	30%
Crew Reference to Just (1) Alert Component	14	22%
No Response until Queried by ATC	33	52%
Occurrences in Climb	30	48%
Occurrences in Descent	26	41%
Occurrences in Approach, Cruise or Unknown	7	11%
Reports by Pilots/Crewmen	57	92%
Reports by Controllers	5	8%
Actual Potential Hazard	6	10%

A relatively high percentage of the deviations (57%) were associated with some distraction or temporary increased workload activity, such as looking for traffic, looking at a chart or dealing with a minor problem, etc..

In many of the situations, the crew occupied themselves with the distraction to the extent that a double check (or even single check) on acquiring the required altitude was no longer maintained. In (54%) of the "busts" a lack of double check was apparent. This number also includes those occurrences where

only one pilot listened to the clearance (and got it wrong) or one pilot mis-set the Altitude Alert.

A clearance misunderstanding was responsible for (32%) of the deviations. This is a significant number. It underlines the importance of both crew-members listening to (and agreeing on) the clearance as well as a requirement to "read it back".

One report included a very interesting suggestion: "...That the Altitude Alert setting be transmitted back to the ground". This is feasible with the development of the data link technology. The potential error reduction includes not only the 32% of clearance misunderstandings, but a portion of the 11% additional deviations where the clearance was understood at the time, but a mis-set altitude alert became a factor later.

Probably one of the most significant statistics is that the Altitude Alert (correctly set) was not seen or heard in 38% of the incidents. The aural Altitude Deviation Alert (usually one C-chord tone/beep) is apparently degraded by the fact that it is also used for the Altitude Approach Alert -- a very common cockpit sound. It would certainly appear that the deviation aural alert should be distinctly different or repetitious until the deviation is corrected (or reset).

The reports referred to a single deviation alert component in 22% of the cases - usually the aural. This suggests limitations in the visual signal as well, since most transports have both. The deviation alert light is usually repetitious, but it is frequently colored blue or white. An inference or a direct comment on the inadequacies of existing Altitude Alerting was noted in 38% of the reports.

The problem has been most acute with the smaller transports, as indicated by the 38% "busts" in the 737, DC-9 category, and an additional 22% for even smaller aircraft. The smaller transports have a far greater exposure, hear the C-chord more often, etc.. Conversely, only 2 of the 63 reports are

believed to have been from wide-body aircraft. The wide bodies (and later model 737's, DC-9's and 727's) are noted to have autopilot altitude captures.

There has been some industry and government recognition of the problem. Federal Aviation Regulation (FAR) 91.51 originally required both aural and visual alerts for altitude approach and altitude deviation. Amendment 91-142 dated August 22, 1981 permits a configuration with only visual signals for altitude approach and an aural signal for deviation. The rule revision is an attempt to make the aural alert more effective for "deviation" by deleting its requirement for "approach". At least one major airline (United Air Lines) is in the process of modifying existing fleets to this configuration.

3.4.2.2 GROUND PROXIMITY WARNING SYSTEM ALERTS

Thirteen reports were reviewed involving terrain warning devices. Of these, ten incidents were associated with airborne systems, two were tower-reported low-altitude alerts, and one was an enroute controller-reported terrain alert. Of the ten airborne system alerts, two represented probable system malfunctions, the remainder being valid alerts, i.e., the GPWS was operating as designed.

The most common cause (4 cases) of the valid GPWS alerts was a pilot-induced alert by making a steep descent to the final approach path during visual approach. This is generally attributed to poor planning on the part of flight crews. Contributing factors were ATC altitude restrictions (3 cases) and reduced visibility (1 case).

The second most common cause (3 cases) of valid GPWS alerts was associated with ATC vectors into areas where Mode 2 warnings were generated due to terrain clearance and closure rate, even though the aircraft was in level flight or a shallow descent. These occurrences indicate a basic incompatibility between ATC procedures and GPWS design criteria.

The remaining valid GPWS alert was attributed to high sink rate caused by severe atmospheric conditions during approach.

Of the tower-reported low-altitude alerts, one was attributed to altitude loss associated with severe atmospheric conditions, and one represents a probable poor calibration of tower equipment.

The ATC-reported terrain alert was associated with ATC vectors into rising terrain for traffic purposes.

It is interesting to note that 60% of the airborne GPWS alerts were associated with causal factors involving ATC procedures, while only 20% represented probable equipment failures. The ATC procedures involved were vectors over rising terrain and late descent clearance for visual approaches. The latter is not considered a particularly significant GPWS problem, since they occur in visual conditions and the flight crews are generally aware of the cause of the alert.

On the other hand, the ATC vector over rising terrain in instrument conditions clearly represents a significant problem in that the flight crew is faced with the choice of ignoring the alert or leaving an assigned altitude, both of which are potentially hazardous.

3.4.2.3 FALSE ALARMS

The ASRS categorized only 20 false alarms from 7/1/76 to 2/2/80 in a total of nearly 18,000 reports. This is remarkable in itself, but it is more remarkable considering that 2 of the reports concerned the same incident, 3 others were of ground-based origin, and 6 were GPWS -- 5 of those 6 were from the dubious ASRS Data Base 1 which was compiled during the period of the introduction and the difficult adjustment for GPWS.

Four alarms were for engine fire - probably all really false - but still a very low number overall. The low number of false alarm reports is impressive.

Two of the ground-based reports involved false glide slope indications on

Instrument Landing System (ILS) approaches, one of them on the "back course". False glide slopes are not an unusual phenomenon and have become more common with our more advanced airplanes using higher sensitivity glide slope receivers for improved autopilot performance. One obvious solution is to clearly indicate on approach charts those ILS installations where false glide slope characteristics prevail (front or back course).

Overall, while it is not intended to be a criticism of ASRS, it seems that airborne false alarms (and warnings) have been a more significant problem than indicated by only 20 false alarm reports out of 18,000 total ASRS reports.

4.0 TASK TWO—EXAMINATION OF THE COCKPIT ENVIRONMENT

The examination of the cockpit environment consisted of riding in the flight station during commercial airlines flights to observe cockpit activity and flight operations and to obtain pilot comments on (present day) systems that are predominant in the fleet today.

4.1 OBJECTIVES

The objectives of this task were to familiarize the investigators with the operational environment, to identify the factors which influence pilot performance, to obtain an input from the line pilot community regarding alerting system operation and function, and to obtain a baseline for assessing alerting system performance and proposed improvements. The investigators participated in routine commercial flights to observe and record cockpit operations, procedures, and crewmember activity. The task permitted the investigators to observe the compatibility of equipment and procedures under the influences of operational environment, weather conditions, communications requirements, crew coordination, and crew activity. In addition, the task provided the investigators with an improved understanding of the operating environment to better understand accident data and the frequently complex evolution of aircraft accidents.

4.2 TECHNICAL APPROACH

The philosophy of the examination of the operational environment was to observe, first hand, flight operations during routine airline flights. A mixture of flights were made; some were flights of long duration and some were short hops. A mixture of daylight/darkness, VFR/IFR and even 2-man crew/3-man crew flights were made. The nature of the project was explained to the crew, and the flight crews responded to questions and commented on crew alerting and operational procedures. The investigators maintained a low profile and did not interfere with normal crew activities.

The investigators, through the course of the task, were able to observe and accompany the flight crews through all the steps of a typical flight from pre-flight through post-flight.

4.3 PROCEDURES

It was necessary for each participating team member to request jump-seat authorization directly with the airline on which flights were desired. Jump-seat is the term applied to the extra seats in the cockpit, normally empty, but available for authorized observers. The airline, in turn, forwarded the request to the FAA. The FAA provided written permission, in accordance with FAR 121.547(c)6, for the investigator to be admitted to the flight deck of the aircraft of that particular airline. The team member then worked with the airline to arrange an itinerary of flights.

To make the most effective use of the flight time and to ensure that the team members' activity was consistent, a data collection form was developed. The cockpit observation form, shown in Appendix B, consisted of three sections. The upper portion of the data form provided space for biographical and flight data to identify the particular flight. This data included the names of the crewmembers, the name of the airlines and the flight number. It also included the time, date, type of aircraft, and point of departure and destination.

The remaining portion of the front page was the observer's checklist. It was divided into flight segments and provided a list of items of interest to be observed. The list provided the observer with reminders of what to watch for, such as pre-flight activity, take-off procedures, and crew activity during approach to landing. The list also provided a reminder to note certain items which might be useful later, such as use of checklists, autopilot, and the alerting system. The back side of the form provided space for writing up any alert that might occur during the flight and for a post-flight narrative and general notes.

A cockpit observation form was initiated for each of the 52 flights. Some of the flights were segment-legs of longer routes flown by the crew, such as Western Airlines Flight 478 which runs from Denver to Minneapolis with three stops enroute. Routes and airlines were chosen to provide a wide cross-section of aircraft types and flight lengths. On occasion, the flight crew was followed through all of their flight legs to observe their full flight schedule.

4.4 RESULTS

The 52 flights, comprising 100.8 hours of flight time, produced observations and comments that ranged from often-repeated to single observations. Observations which were frequently noted included the prevalence of untimely alerts, the low incidence of alerts, and the scattered alert locations in fleet aircraft.

4.4.1 NUISANCE ALERTS

A problem with current crew alerting systems was found to be that of nuisance alerts, which consist of unwanted, unnecessary, or untimely alerts. Pilots were critical of getting alerts when no threat existed, or when the situation was pilot induced and anticipated. Examples of these include the configuration alert when the action of reducing power for let-down was mismatched with the up position of the landing gear. The crews customarily inhibited the "gear not down" alert in those situations. Another alert, frequently encountered, was that of the altitude alert. This alert, described in Section 3.4.2.1, is a source of concern in that the same C-chord tone is used to announce an ALTITUDE DEVIATION alert as well as the frequently-heard ALTITUDE APPROACH alert.

Other alerts which were termed nuisance alerts involved terrain warning devices. The most common of these alerts was the pilot-induced alert caused by a steep descent to the final approach path during visual approaches.

Whether caused by a late descent clearance or by a letdown at pilot's discretion, the result was a rapid descent which triggered the alert. The second most common GPWS alert was the ATC-induced alert for terrain clearance. These alerts are associated with ATC vectors over hilly terrain.

The pilots were also critical of getting low-urgency alerts when they were busy flying the airplane. Almost all the takeoffs and landings were flown manually. Most airlines had some policy concerning conversation in the cockpit during these flight phases, and on one occasion, a flight engineer refrained from informing the pilot of a slight rise in constant-speed-drive oil temperature during takeoff. During these high-activity flight phases conversation was limited to the challenges and responses to the various checklists, the speed call-outs during takeoff, and the altitude and speed call-outs during landing.

4.4.2 FREQUENCY OF ALERTS

No alerts that required a response were observed during the 52 flights, nor were any false alarms observed. All the altitude alerts and the GPWS alerts which were defined as nuisance alerts were proper alerts generated by properly-operating equipment.

4.4.3 VARIETY OF DISPLAY LOCATIONS

A wide variety of crew alerting designs and display locations were observed. Data was gathered in 737, 727, DC-10, and L1011 aircraft. While all the crews were used to their cockpit display layout, some crews complained that the alert lights were too spread out, and there were too many alerting tones. These observations support earlier findings (Ref. 3).

4.4.4 MISCELLANEOUS OBSERVATIONS

In addition to the primary concerns discussed above, other comments and observations were:

- All flights were flown without incident
- There were no missed approaches made
- On one occasion an aural alert blocked out an ATC call
- Some crews complained of high noise levels in the cockpit
- Some crews expressed a need for better ground/ramp control
- All the crews were concerned with collision avoidance, especially during takeoff and landing.

5.0 CONCLUSIONS FROM TASKS ONE AND TWO

5.1 LIMITATIONS OF THE DATA BASES

Two data bases were developed in the study. One data base came from NTSB-type reports and the second was drawn from the ASRS. The term NTSB has been used throughout this report to identify all data sources, other than the ASRS. Because of the significant differences between the data recorded in the NTSB accident reports and the data recorded in the ASRS reports, the ASRS data was collected, analyzed, and reported separately. The ASRS reports were provided by the FAA contract monitor; the NTSB data was collected, or already held, by the participating companies. The NTSB data base was the primary source for the data used in the study. The ASRS provided supporting or supplementary data.

5.1.1 LIMITATIONS OF THE NTSB DATA BASE

The NTSB data base consisted of 160 accidents/incidents. Data was drawn from accident reports from NTSB/CAB, foreign government, ICAO, and in-house files. Of the 160 accidents/incidents examined 99 were hull-loss accidents, 20 resulted in substantial damage, 27 resulted in minor damage, and only 14 resulted in no damage to the aircraft.

While such figures indicate quantity in a data base, they don't readily convey the quality, or content of the data. The types of accidents in the data sample, whether the airplane was destroyed, whether there were survivors, can affect an analysis of causal factors, crew performance, and alerting system operation. In determining the probable cause(s) of an accident, all facts, conditions, and circumstances are considered by the accident investigators. The objective is to ascertain those cause-and-effect relationships that existed in the accident sequence. If the crew doesn't survive so there is no one to interrogate, the course of the investigation is committed to sifting through the wreckage, studying the clues and the voice and crash recorders, and attempting to determine what the airplane did and what the crew did.

A majority of accidents which result in the destruction of the aircraft are determined to be caused by crew error. In a recent study of 609 accidents of all types, crew error was cited as the probable cause in 66.4 percent of them (Ref. 6). The figure jumped to 77.4 percent when only hull-loss accidents were considered. Since 293 of the 609 accidents were hull-loss, the percentage of crew error in the non-hull-loss accidents was about 56 percent. These data indicate that crew error was cited as the probable cause for accidents more frequently when the aircraft was destroyed.

The data from this accident review also showed a correlation between loss of aircraft and crew causal factors. The analysts reported 43 accidents for which only one cause was apparent. The relationship of causal factor to aircraft damage sustained is shown below:

		Aircraft Damage			
Number	Causal Factor	Destroyed	Substantial	Minor	None
21	Cockpit crew	21	0	0	0
3	Weather	1	0	2	0
9	Mechanical	3	1	2	3
0	Operations	0	0	0	0
3	Other	2	0	0	1
7	Unknown	5	1	1	0

It is noteworthy that every crew-caused accident was a hull-loss accident. Equally important, however, is that when the crew is lost with the aircraft, little data is available to evaluate the performance of the crew or the alerting system.

Selecting a large number of hull-loss accidents to review carried a penalty for the survey. Although selecting a large number of hull-loss accidents portended a large number of crew-error accidents in the sample, the accident

summaries provided a minimum of data on crew activity and alerting system performance.

5.1.2 LIMITATIONS OF THE ASRS DATA BASE

ASRS reports are submitted voluntarily by participants in the aviation community. After preliminary processing, all ASRS reports are marked so that there is no way to identify individuals submitting or named in the reports. ASRS reports tend to be sketchy by nature, however further "sanitizing" of the reports has been practiced. It is suggested that additional data such as airplane model and dates should be made available to legitimate research efforts. A more detailed submittal form requirement and a more detailed follow-up (CALL BACK) would enhance the system.

The ASRS was initiated in July 1976. In May 1978 significant improvements were made in the data processing which resulted in a higher quality system. The data from both time periods were reviewed, but a priority was given to the later, improved system reports.

5.1.3 LACK OF CREW AND ALERTING SYSTEM PERFORMANCE DATA

It became evident during the examination of the NTSB accident data that there is a paucity of data in the accident/incident reports concerning crew performance or the status or activity of the crew alerting system. Such data would have been extremely useful in this study and would enhance any assessment of the performance of the alerting system in future accidents/incidents. Such data would be of great value especially in accidents in which no flight crew members survive. Two methods to collect such data have been suggested. They are wide-angle video cockpit recording and recording of the operation of both the visual and aural alerting devices in the cockpit.

5.2 CONCLUSIONS FROM THE EXAMINATION OF ACCIDENT DATA (TASK ONE)

5.2.1 CRITICAL FLIGHT PHASES

The data shows that certain phases of flight produced more accidents than others. Sixty percent of the accidents occurred in three of the nine phases of flight defined for the study. Takeoff produced 21 percent of the accidents, while final approach contributed 23 percent and landing contributed 16 percent.

5.2.1.1 TAKEOFF, FINAL APPROACH, LANDING PHASES

The data showed that during takeoff mechanical causal factors were reported more frequently than crew errors. Maximum performance is required of the airplane during takeoff, while the pilot's task is to monitor the performance of the airplane and to guide it into the air. During this phase, the most critical pilot task is to decide to take off or to abort the takeoff. The decision is based on the performance of the airplane relative to the runway and weather parameters. The crew utilizes all available information to make the decision including out-the-window, cockpit instrument, and operation manuals as well as pilot training and experience.

The accident data also showed that final approach and landing were critical phases of flight. During these two phases, crew errors were cited more frequently than mechanical failures, with a ratio of 55 to 4 in final approach and 36 to 8 in landing. In these two phases of flight only 12 mechanical causal factors were reported, however, the number of crew errors in navigating and controlling the airplane to a safe landing on the runway showed them to be critical phases for the flight crew.

5.2.1.2 EFFECT OF CRITICAL FLIGHT PHASES ON CREW PERFORMANCE

During takeoff, final approach, and landing, the aircraft is exposed to the hazard of an inadvertent collision with the ground. In these flight phases, the crew experiences the greatest workload, activity, and opportunity for unreconcilable errors. Crew error was found to be the principal cause for accidents in the final approach and landing phases, and, although mechanical failures were more numerous than crew errors in accidents during takeoff, the flight crew is responsible for safe recovery from those mechanical failures.

In other phases of flight relatively few accidents occurred. For example, although the cruise phase of flight accounts for 64 percent of the operational time of a typical flight, it accounted for only 6.1 percent of the accidents (Ref. 6). Climb-out and descent also accounted for relatively few accidents, but they contain the transition events leading into and out of cruise and require considerable crew activity.

5.2.2 MULTIPLE FACTOR ACCIDENTS

The data indicates that most of the accidents were not the result of a single failure, deviation, mistake, or misjudgment; they were the result of accumulating or compounding problems. They were shown to be the result of multiple causes, primary and contributing.

Over 73 percent of the accidents examined indicated multiple causes for the accident. Twenty-seven percent of the accidents were the result of a single causal factor, 40 percent were the result of 2 causal factors, and 23 percent were the result of 3 causal factors.

The NTSB data base from the 160 accidents reviewed contained 177 cockpit crew errors along with 87 mechanical, 49 weather, 10 operational, and 20 "other" causal factors. Since only 21 of the accidents were the result of a single cockpit crew error, it is apparent that the majority of crew errors were

committed in conjunction with other factors, including other crew factors. Many of the crew errors were the result of improper responses to situations precipitated by other causal factors. In such cases, instead of the crew providing a recovery from the situation, they often aggravated it.

5.2.3 ANALYSIS OF CREW ERRORS

Considering both primary and contributing causal factors, crew errors outnumbered mechanical failures by 177 to 87, or over 2 to 1. When only hull-loss accidents, which generally occurred in the critical flight phases, were considered, errors attributed to the crew outnumbered mechanical failures by 132 to 24, or 5.5 to 1. This difference supports a suggestion that high crew activity and increased workload provide an environment conducive to crew errors.

5.2.3.1 CREW ERRORS AS THE PRIMARY CAUSE

The analysis of the 160 NTSB accidents/incidents showed that in 21 accidents, crew error was the primary cause and no other cause was reported. The most frequently reported crew errors were:

- Misjudged speed, distance, altitude, clearance, etc. (29%)
- Navigation error (19%)
- Failed to follow approved procedures (14%).

This set of accidents consists of only hull-loss accidents and was discussed in a previous section. No further breakdown of the accident causal factors was made; recourse to the NTSB accident histories could possibly reveal further details such as the precise navigation error made, or what flight parameter was misjudged. The causal factor, "FAILED TO FOLLOW APPROVED PROCEDURES, DIRECTIVES, ETC.," is somewhat of a "catch-all" selection. An earlier study suggested that the investigators stopped short in not determining why the pilot failed to follow approved procedures in a particular accident in question (Ref. 7).

5.2.3.2 CREW ERRORS AS A PRIMARY CAUSE

The NTSB data showed that when crew error was listed as a primary cause, 150 times, the errors most frequently cited were:

- Failed to follow approved procedures, directives, etc. (21%)
- Misjudged speed, distance, altitude, clearance, etc. (14%)
- Selected wrong action/took no action when one was required (11%)
- Inadequate supervision by the pilot in command (8%)
- Improper application of controls, brakes, flaps, etc. (7%)
- Navigation error (6%)
- Instruction (person-to-person) - Misunderstood/ambiguous/not received (6%).

Several other crew errors which were reported less frequently, but which warrant attention include:

- Attention diverted from required task (7 times)
- Failed to use proper emergency procedures (3 times)
- Took too long to initiate proper action (2 times).

5.2.3.3 HIGH INCIDENCE OF SIMULTANEOUS/MULTIPLE ALERTS

Air carrier accidents are extremely complex events; over 73 percent of the accidents examined reported multiple causes for the accident. The data showed that when alerting devices were reported to have been activated, accidents reported to be caused by crew error had over twice as many devices activated, on the average, than when the primary cause was mechanical failure. It indicates that the crews may respond without error when only a few alerting devices were activated, but may make errors when there were many alerts going off.

Several situations can cause a large number of simultaneous device activations:

- o Multiple failures
- o Major component failure--coupled sub-components cease to function
- o A failure annunciated by many devices.

Compounded failures or a confusing barrage of horns, lights, and bells can create the high activity and stressful environment that can cause incorrect responses and failure to follow correct procedures.

5.2.3.4 ANALYSIS OF FACTORS OTHER THAN CREW ERROR

The causal factor categories, other than crew error, which the analysts used were weather, mechanical, operational, and other (non-flight phase related).

When weather was a primary causal factor (sample of 31), factors reported most frequently were:

- Wind (35%)
- Rain/Moisture (19%)
- Thunderstorm/Tornado (19%).

When mechanical factor was a primary cause (sample of 64), factors reported most frequently were:

- Fire/flame/smoke/explosion (16%)
- Corrosion, embrittlement, fatigue (16%)
- Tire failure/wheel failure (14%)
- Power plant (cowling, electrical harness, ducts, etc.) (11%).

When operational factor was a primary cause (sample of 7), factors reported most frequently were:

- Aborted takeoff (29%)
- Ran off runway (29%)
- Taxi (29%).

When "other" factor (non-flight phase related) was a primary cause (sample of 12), factors reported most frequently were:

- Collision (aircraft/bird/other object) (33%)
- Communications with ATC/Company (25%)

- Evasive action to avoid collision (17%)
- Uncontrolled attitude/altitude deviations (17%).

While the above are the causal factors most frequently reported, less-frequently reported factors involved in the accidents reviewed included:

- Hail/sleet/freezing rain (5 times)
- Doors (4 times)
- Flight control (2 times)
- Engine - partial or complete loss of thrust (1 time)

5.3 CONCLUSIONS FROM FLIGHT OBSERVATIONS (TASK TWO)

Although the results from the cockpit observation flights were not supported by large statistical bases, they provided a measure of supporting data for the accident data analyses.

5.3.1 UNTIMELY ALERTS

Current caution and warning systems too frequently present alerts to the crew when they are not wanted. Pilots commented on getting low-urgency alerts during certain critical flight phases and getting alerts for situations which pose no threat.

Several crews adhered to a no-conversation policy below certain altitudes; this included an instance where a flight engineer refrained from calling out a minor oil temperature deviation during takeoff roll. The pilots also commented on getting configuration alerts during descent when the power was reduced with the gear not down; most crews manually inhibited the aural alert.

Other pilot comments were related to nuisance alerts. The most prevalent nuisance alerts were the altitude alert and the terrain avoidance warning of the GPWS. On the flights monitored, the altitude alert sound was activated in nearly every descent from cruise altitude into the destination terminal airspace. After receiving ATC clearance for a step-down descent, standard cockpit procedure is to set the new required interim altitude into the altitude-select panel and arm the system. The problem with this procedure is that, during the step-down descent phase, new altitude clearances are not always issued by ATC in time, and the system activates the alert as the aircraft penetrates the set-in altitude. A greater problem with the altitude alert, not mentioned by the flight crews, is that the system has two functions which conflict. The aural Altitude <u>Deviation</u> Alert, signalled usually by a single-stroke chime, can be degraded by the frequent use of the same signal to annunciate an Altitude <u>Approach</u> Alert, which is a very common event. The use of a signal to annunciate a "reminder" is counter-productive to the use of that same signal to announce an abnormal sitaution. Changes in the regulations for altitude alerting were implemented by the FAA in Amendment 91-142 dated August 22, 1981.

The terrain avoidance alert, a synthetic voice presentation from GPWS, was regarded by some pilots as a nuisance because of its distracting sound and intrusiveness in situations where they felt there was no threat. Two flight operations which create these situations are: (1) when the crew descends too fast (knowingly) into a terminal area in VMC and, (2) when the terminal approach controller vectors the aircraft over mountainous terrain. The former, creates a nuisance alert because the crew intentionally created the situation. The second is also a nuisance, especially if the crew is confident of the controller in IMC, or if conditions are visual. It must be pointed out that the GPWS operated as it was designed in these situations.

5.3.2 LOW INCIDENCE OF ALERTS

Discounting the nuisance alerts, there were no alerts observed in the 52 flights. There were occasions such as having a delay in gate departure due to a "doors" light indicating an unsecured door, but no inflight, non-nuisance alerts were observed. This was not surprising, however, as the industry has attained excellent low failure rates through good aircraft design and maintenance procedures. The majority of causal factors are cited at a rate of less than once a year (Ref. 7). However, continued reduction in failures could lead to a reduction in accidents/incidents since each failure affords the opportunity for error in response to the failure.

5.3.3 SCATTERED ALERT INDICATIONS

The crews commented on the fact that there were so many bells, whistles, and tones in the cockpit, that it takes a few seconds to determine what sound was activated and what system is associated with that sound. A majority of the pilots and flight engineers stated that, upon receipt of an alert, the relevant alert indicator must first be located and the alert message understood before action could be taken. That process is hampered by the many different locations of the indicators in the different aircraft types. The pilots felt that the alert indicators should be placed in a central location to avoid searching for the alert message. The pilots agreed that the number of tones should be reduced to only a few, and that those few should be standard throughout different types of aircraft. They felt that with only a few alerting tones and appropriate alert lights on a central panel, the crew would be better equipped to handle emergencies in a much smoother and quicker manner. Late aircraft designs have provided centrally located alert annunciator panels.

5.3.4 MISCELLANEOUS PILOT COMMENTS

Collision avoidance was a matter of concern for the crews. They were expressly concerned during departures and arrivals.

The flight crews commented on the importance and criticality of ground control in the terminal area. Many of the pilots were critical of ground controllers that do not provide sufficient information concerning the taxi-way and takeoff areas. Frequent obstructions due to construction, and heavy traffic during peak arrival and departure hours contribute to the problem. The pilots expressed concern that accidents can happen as easily on the ground as in the air. Flight crews suggested that "ramp control" for operations at high density terminals be initiated to relieve some of the congestion and confusion.

Finally, the pilots commented on the problems of distractions. Some of these comments were couched in comments about nuisance alerts, but others were not. Distractions need to be defined and kept in perspective and context. A distraction can be grossly defined as something which detracts from something more important. Dependent on what the crewmember is doing, some event can be a "distraction" in one situation, but be a necessary intrusion in another. Such is the case with the GPWS terrain alert. When occurring as a result of a situation intentionally induced by the crew, the GPWS alert is called a distraction, but when the situation is unintentional and hazardous, the GPWS alert is a welcomed intrusion.

Besides comments on the distracting effects of nuisance alerts, other distractions that were identified included: airplane sub-system noise infiltrating the flight deck, talking to the passengers on the public-address system, radio and personal voice transmissions, and shuffling for charts, approach plates, and other documents in the cockpit.

6.0 IMPACT OF FINDINGS ON ALERTING SYSTEM DESIGN

Aircraft accident rates can be reduced by several means, including: improving the airways system, aircraft design, pilot performance, airline policies and procedures, and crew alerting. Implications from previous studies suggest that accident rates can be reduced by improvements in crew alerting.

These studies have shown that current fleet aircraft have many alerting devices and methods. This has come about because of a lack of industry standardization and because crew alerting has not been designed as a system with defined functional requirements. These shortcomings can be corrected by adhering to the Alerting System Design Guidelines (Ref. 5). It also appears feasible that the alerting system described in the Guidelines can be expanded to provide flight status monitoring. Such a system would provide crew alerting for operational abnormalities as well as aircraft system failures. Based on the conclusions, such a system must consider additional alerts, and several other functional requirements.

6.1 NEED TO CONSIDER FLIGHT PHASE

The examination of accident data and the flight deck environment showed that 60 percent of the accidents occurred during takeoff, final approach, and landing. These critical flight phases are characterized by increased crew activity and crew coordination. The flight crew should be protected from distractions from the piloting tasks during these phases of flight. The evaluation of the need for response to an alert can only be made if flight phase is taken into account. It follows that a flight status monitor requires flexibility and adaptability to accommodate changing operational and updating requirements.

6.1.1 EACH FLIGHT PHASE UNIQUE

Each flight phase has one basic purpose; for instance the basic purpose of final approach is to fly the aircraft according to a specific descent profile until the decision height is reached and then to make the transition to outside visual references for landing. If for example, a multiple failure involving a major system and associated subsystems were to occur at this time, excessive demands on the information processing capabilities of the crew could be imposed thereby having a direct impact on the safety of the flight.

The pilot's capacity to cope with increasingly complex situations and sub-systems will, in part, depend on the patterns and skills that he/she has developed over years of flying. When situations occur that require actions outside the capacity of learned patterns and skills, pilot's performance, unaided, may slow markedly. Some emergencies did not follow pre-established scenarios for fault diagnostics and corrections. Also, worst case considered, there is no way to predict how the stress of sudden demands of a multiple alert may affect the crew's performance. Some emergencies cannot be handled by going strictly by the book. The available information may be incomplete and misleading for the situation, thereby affecting the pilot's mental picture of aircraft status.

6.1.2 SAME ALERT-DIFFERENT EMPHASIS BY FLIGHT PHASE

The response to an alert must be weighed against the other tasks the pilot has. Some of the more critical phases of flight during which emergencies occur may leave only enough time for an immediate reaction by the pilot. In some situations, a pilot's response may be more influenced by habit pattern developed through training and experience than by the process of inductive or deductive reasoning. In any case, the crew must consider each alert in the context of all the tasks and activities going on at that time.

Digital processing techniques provide the opportunity for systems designers to incorporate new and improved functions in the alerting system logic. That software logic should contain provisions for flight phase adaptation by the aircraft systems and consider all combinations of failures and external conditions.

According to the Alerting System Design Guidelines (Ref. 5), the criteria for a warning and caution alerts is stated as follows:

WARNING:	Emergency operational or aircraft system conditions that require <u>immediate</u> corrective or compensatory crew <u>action</u>
CAUTION:	Abnormal operational or aircraft system conditions that require <u>immediate</u> crew <u>awareness</u> and require prompt corrective or compensatory crew action

Engine fire is always assigned the urgency level of warning, however the sophistication and reliability of aircraft and engines today have changed crew procedures for engine fire during takeoff. A fire warning beyond a V_1 reference speed is left unattended until the aircraft is safely airborne, a positive rate of climb is established and the gear retracted. Those objectives are met before the crew takes corrective action on the engine fire. This procedure is quite valid when considering the following:

1. The fire warning may be false and shutting down the engine unnecessarily introduces marginal climb performance.

2. An engine on fire, may for a limited period of time develop some thrust, thus making the initial climb-out flight phase less critical.

3. During the highly critical takeoff phase the pilot should not be distracted by actions not relevant to achieving sufficient obstacle clearance.

4. The time delay in closing the fuel valves and activating the fire agent bottle will usually be in the order of seconds, not minutes. The engine fires today are not as detrimental to the structural integrity of the airplane as they used to be.

There can be little argument that engine fire constitutes a high-priority emergency to which the pilot must be alerted. We have therefore, arrived at a paradox that on one hand we require immediate action when a warning alert is activated, but on the other hand instruct the crew to disregard the warning for a certain period of time.

Another example of this paradox is pitot heat failure. During low altitude operations, a pitot heat failure may have fatal consequences in a very short time because freezing moisture can plug up the pitot tube causing erroneous airspeed indications. However, at flight level 350 and an indicated outside air temperature of thirty degrees below freezing, pitot heat failure is relatively harmless and requires no immediate crew action. Another example is the landing gear configuration alert. When it sounds during initial descent from cruise altitude it is just a nuisance and most first officers observed automatically silenced it with a cut-out switch. But when it sounds on final approach, it does indeed warrant immediate crew response.

Summarizing, it becomes clear that with current training, the pilot is required to anlayze all alerts irrespective of their expressly-designed significance, i.e., evaluate their urgency relative to the actual circumstances (flight-phase), and only then decide on what action to take. If the aircraft is in a critical flight phase, with a correspondingly high workload in the cockpit, this requirement to evaluate all alerts can lead to an excessive workload and contribute to the development of accidents/incidents. The use of alert prioritization, adaptive by flight phase, should ameliorate this situation.

6.1.3 INHIBIT LOW-PRIORITY ALERTS BY FLIGHT PHASE

Low-urgency alerts can disrupt and confuse crew activity during critical flight phases. Unnecessary alerts distract the crew and may cause them to miss more vital alerts or make errors in critical flying tasks while searching for their solution. Early studies showed that pilots felt there was a potential for too many alerts in critical operating regimes, and suggested an inhibit scheme for the takeoff and initial climb phases of flight (Ref. 3). Each alert should be tested for its significance relative to the flight task. Any alert which fails the test should have the most distracting of the alerting components inhibited during that flight phase.

6.2 NEED TO DEAL WITH MULTIPLE CAUSES

The data base showed that in 73% of the accidents/incidents surveyed there were multiple causes. It is expected that there will be multiple system abnormalities even when precipitated by a single system or crew failure. In addition, there can be failures precipitated by multiple and unrelated failures over a short period of time. When these alerts are presented to the crew in the form of multiple and simultaneous alarms, the crew can be immediately overloaded. On the other hand, it appears feasible to provide a digital computer with the proper logic to quickly and reliably determine the relative criticality of the alerts and display them to the crew for their response. Of course the required logic must be developed, analyzed and subjected to exhaustive testing to insure complete and reliable coverage of the failures and the recovery process and to determine if the improvements are consistent with predictions.

6.2.1 ALERT PRIORITIZATION AND INHIBITION

Alert prioritization and inhibition can help the pilot respond to multiple alerts. For alert prioritization, the alerts in each urgency level should be automatically prioritized by the system so that when a particular fault occurs, the message would appear on the display in its appropriate position relative to the other messages of the same category already present. With this approach, the most important message would always be at the top of the

displayed alerts in its category, regardless of time of occurrence. The application of alert inhibit logic would inhibit low-urgency alerts during high workload flight segments.

In an earlier phase of the present study, it was determined that an effective prioritization system would have to be flight phase adaptive. Another finding from the study was the high degree of variability with which the subject pilots prioritized a given set of alerts. The variability was not surprising, considering that the 21 pilots came from a variety of organizations and aircraft types. Two issues became apparent. First, if prioritization and inhibit logic are utilized, they will probably be aircraft and airline specific. Secondly, the development of the actual prioritization order will need to be carried out by design engineers as well as pilots. A combination of flight experience, aircraft familiarity, and design expertise will yield a more effective prioritization system than any one of these capabilities would yield by itself.

A flight simulation study performed during the same period showed the efficacy and need for prioritization and inhibits. The simulation supported the following conclusions:

1. In multiple failure situations, pilot performance improved significantly when alert prioritization was employed.

2. When alerts were not prioritized, performance was significantly better when inhibit logic was employed to delay the presentation of non-essential information on the display (Ref. 8).

6.3 NEED FOR A CHECKLIST CAPABILITY

This study showed that a large percentage of incidents resulted from crew error and in particular from taking the wrong action or no action. Emergencies are often compounded by increased crew workload. One way to reduce workload and human error would be to computerize the emergency procedures which are presently incorporated in emergency and abnormal procedures section in the flight manual and/or in cockpit cards. For some alerts the ability to manually call up the procedure checklist onto a CRT display might be desireable, while in other cases, automatic presentation of the checklist

might be more appropriate. Some emergency procedures might be abbreviated with automatic reconfiguration of parts of the subsystems. All of these varying degrees of computerization may be used to reduce the problems of wrong or no action by the crew.

The incorporation of this checklist capability may also increase the number and variety of emergencies which can be handled. The present limitations are in the number of procedures which can be committed to paper and/or memory and reliably and quickly recalled in the air during an emergency. With vastly improved memory and access capability available in advanced data handling systems, the number of catalogued emergency procedures might be increased, the limitation being the engineering man-hours necessary to design, analyze, test, and validate the procedures.

6.4 NEED FOR ADDITIONAL ALERTS

The examination of accident/incident data indicated the potential benefit of the following alerts.

6.4.1 NAVIGATION ERROR

The data showed that when crew error was a primary cause, approximately 6% of the errors were navigation errors. Navigation error, other than equipment failure, can be of such varied forms that a general treatment is not productive. The sensing of error when a pilot misinterprets the compass heading, sets in the wrong VOR/ILS station, or lands on the wrong parallel runway is unlikely. However, errors due to equipment malfunction, failure of the pilot to follow a desired course, or flight into hazardous terrain can be announced to the crew. Also, future terrain avoidance systems using ground based navigation systems should have an interface with the alerting system.

6.4.2 WIND

Wind was cited as a factor 12 times in the 160 incidents reviewed. It is unknown how many involved wind shear. Commercial transport aircraft having inertial sensors require relatively little effort to provide wind shear protection. Non-inertially equipped aircraft would require additional equipment/sensors to provide this capability.

6.4.3 TIRE/WHEEL FAILURE

Tire/wheel failure was cited 10 times in the 160 accident histories, and all of them occurred during the takeoff roll. Low tire pressure, leading to eventual tire failure, was a frequently cited condition. The failure of one tire often led to failure of adjacent tires, which in some cases resulted in the total collapse of the landing gear, a wheel well fire, and the severing of hydraulic lines. Detection of tire under-inflation or failure before start of takeoff run could reduce or eliminate this accident causal factor.

Some of the most tragic accidents associated with tire failure occurred when the aircraft either ran off the runway in trying to abort the takeoff or was unable to gain sufficient speed to lift off with adequate clearance. With the availability of tire/wheel sensors and computational capability, computerizing the abort decision process is possible.

6.4.4 COLLISION AVOIDANCE

There were only a small number of collision or near miss incidents in the data base; however, the results of a mid-air collision are so traumatic that collision alerts and collision avoidance occupy a strong position in the concept of an alerting system. There have been dramatic collisions in the air and on the ground: the San Diego mid-air collision and the Tenerife collision of two 747 aircraft on the ground. In previous phases of this study, a time-critical display function was identified as being the recommended display for collision

avoidance. Poorly designed systems might have too high a false alarm rate to be useable. Therefore, although it has been established that collision avoidance systems may be helpful and that the displays proposed are reasonable, continued study is needed to establish the traffic collision avoidance system.

6.4.5 ABORTED TAKEOFF

Section 6.4.3 discussed the potential reduction of accidents in aborted takeoffs due to tire and wheel failure. However, a general consideration of aborted takeoff should include all other failure modes. The accident data showed that engine malfunction was the most common cause for aborted takeoff. It is noted that tire/wheel failure resulted in more serious accidents (hull loss and fatalities), but engine malfunction caused more incidents. At any rate, aborted takeoffs was a causal factor in a significant number of incidents. The best means to present the alert to the crew (if one is to be presented) has not been established. The presentation could be an alphanumeric time-critical alert, "ABORT", or it could be a continual graphic presentation of the runway remaining. The selection of the continual presentation would afford the pilot more opportunity to monitor, check and make an appraisal of the abort criteria. More study is required to establish the optimum presentation method.

7.0 ADDITIONAL REQUIREMENTS FOR A FLIGHT MONITOR APPLICATION

7.1 GENERAL REQUIREMENTS

A flight status monitor should include the functions of crew alerting. The following display components were recommended in "Aircraft Alerting System Design Guidelines", (Ref. 5):

1. Master Aural Alert - to attract the crews attention and provide preliminary alert-urgency-level information.

2. Master Visual Alert - to attract the crew's attention and provide preliminary alert-urgency-level information.

3. Visual Information Display - to provide a location where all warning, caution and advisory messages can be displayed.

4. Voice Information Annunciator - to provide voice messages when rapid action is required or to transfer workload from the visual to the auditory channel.

5. Time-Critical Warning Display - to provide guidance for immediate action necessary for flight safety.

In the practical application of these concepts to new aircraft, it is apparent that although all aircraft need standardization for the benefit of uniformity of crew training, the functions, hardware and logic may be different for different aircraft and airlines. The small commuter airliner with twin turboprop engines may not be able to afford the weight, cost and panel space for duplicate, dedicated displays. However, large commercial aircraft may need, and have the space for, duplicate displays with a number of sensors and sophisticated interfaces with the flight management, data processing, fault monitoring and air data systems. Yet, both of these aircraft types should have basic standardization between them; that is, a certain tone, light, color or message

wording should have the same meaning to the crew whether in the commuter aircraft or the international carrier. Of course, even for these displays, the number of messages and the logic by which they are derived will be different for the two aircraft because of the different engines, system equipment and airline procedures involved.

Multipurpose displays can be used to display emergency procedures checklists to provide the crew with guidance on the appropriate corrective action.

The visual information display would, in most applications, be an element addressable display such as a cathode ray tube or a flat panel display. However, for the smaller aircraft, the lighted label or switch panel display, presently widely used, would probably be utilized and therefore should be designed in accordance with the standardization of message format and color usage recommended in the Guidelines.

To summarize the application considerations:

1. All next-generation commercial aircraft should have master visual alerts, master aural alerts, a visual information display, a voice information display, and a time-critical warning display.

2. The master visual alerts, master aural alerts, and time-critical warning display should be standarized, but tailored specifically for each aircraft design as discussed in the Guidelines.

3. The visual information display will vary in size and mechanization to accommodate various aircraft capabilities. However, the messages should be standardized, and the location in the aircraft should be as recommended in the Guidelines.

4. The voice information annunciator should be implemented according to the Guidelines.

5. A display for emergency procedures and checklists is recommended. It must interface with the control and display functions in the aircraft.

6. The logic, algorithms, and amount of interface with other onboard systems will vary with each aircraft type and airline user, however, much will be similar. Packaged alerting and warning systems may be practical for smaller aircraft. For the large, more sophisticated aircraft the alerting system should be custom designed and integrated with the flight management, data handling and fault monitoring systems.

7.1.1 INTERFACING

Beyond minimum requirements, there is a place for increased sophistication and improved capabilities that would yield benefits both desirable and feasible for advanced alerting systems. These benefits would come largely by integrating the alerting system with the other data handling systems. It is projected that for future airliners there will be an integration of flight management, performance management, flight control, fault monitoring, maintenance data recording, sensor subsystems, navigation and communications. This does not necessarily mean the use of central computers; digital data buses could enable easy interchange of information between subsystems. The alerting system could thereby have access to all information and could through the use of sophisticated logic, assign priorities, inhibit alerts, and even initiate corrective action. The definition of this logic and algorithms is beyond the scope of this study, however, the handling of emergency situations by automatic reconfiguration, and automatic selection of the options for human consideration will expand rapidly as the technology of data system hardware and software matures. For the present, the elements of the alerting system should be defined to the extent that they can be mechanized to provide a standardized form and function. Industry can then custom-design the logic and

interfaces to the extent that the state-of-the-art and cost effectiveness factors warrant. It seems that the amount of logic involved will vary a great deal from the sophisticated data systems of the large aircraft to the simple and perhaps off-the-shelf versions incorporating not much more logic than present systems. However, in all cases the messages, colors, and tones should mean the same thing to all pilots. Finally, as with all integration concepts, feasibility must be established for a particular design.

7.1.2 INFORMATION PROCESSING

From the foregoing it is apparent that the information processing requirement will vary over a large range, but that in the most capable configurations the information processing function will comprise a large part of the alerting system. The processing will include the logic which prioritizes messages, inhibits messages, decides which checklist is required, integrates checklists for multiple faults, assesses sensor data for system status, and controls the data displayed. The capability of the alerting system will, in all probability, grow with the capability of digital technology. This growth, in turn, will be mainly dependent on the capability of engineers to economically design reliable software. For austere systems, the information processing technology is available today; the major design effort and system expense will be in the area of displays.

As stated previously, the crew interface requirement will cover a wide range of complexities. For an austere system the master visual and master aural alerts will usually be reset manually; a button on the visual alert will suffice for both visual and aural master reset. The visual information display will require controls for line address, store/recall, and checklist functions. These functions could be activated by buttons located along the side of the panel and aligned with the messages, or by other methods such as voice, keyboard, or a touch-panel on the display face.

For the sophisticated systems of the future, store/recall of alert messages and the display control functions will be based on extensive interrelationships with emergency procedure actions and integrated with other aircraft system controls.

7.2 SPECIFIC REQUIREMENTS

7.2.1 FLIGHT PHASE EDITING

The incorporation of flight phase knowledge (taxi, takeoff, climb, etc.) into the logic can be used to prioritize, inhibit and modify alert messages. For example, the alert annunciating a single generator failure or a pressurization failure should be inhibited during takeoff to avoid distracting the pilot and possibly causing an aborted takeoff. Some of this is done on present aircraft but more sophisticated logic is to be expected as the technology improves. The investigation of the logic and algorithms for flight phase editing offers large benefits in terms of reducing the number of false alarms, pilot workload, distractions, and confusion with more important alerts.

7.2.2 PRIORITIZATION FOR MULTIPLE FAILURES

A prioritization scheme should be incorporated in the alerting system as noted in the Guidelines. As a minimum, alerts should be prioritized by urgency level (warning, caution or advisory). The logic required for some of this prioritization seems apparent, however, an in-depth analysis is usually required. The derivation of the logic is beyond the scope of this study. Each situation must be examined in detail for each aircraft, even to the extent of adding sensors or changing sensor locations so that the logic will be error-free.

7.2.3 CHECKLISTS

After the pilot gets the master alert and reads the message on the visual information display, it is often necessary to take action to resolve the problem. At the present time this action is either performed by memory or by referring to an emergency procedure manual or checklist card. In the aircraft of the future with its digital data systems and multipurpose displays, a checklist could be displayed, thus saving precious time in initiating a

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required procedure and also greatly reducing the possibility of human error. Also, different stages of a complicated procedure could be shown in detail with immediate feedback to assure that the correct result has been attained before proceeding to the next step. However, the logic for presentation of the alerts and the procedural checklists must be carefully conceived, analyzed and tested for each particular aircraft type. To achieve maximum results, additional or specialized sensors may be required; but the benefits should be worth the development costs if a significant number of aircraft are involved.

8.0 IMPLEMENTATION CONSIDERATIONS

8.1 INFORMATION PROCESSING

8.1.1 ALGORITHMS

The logic which initiates the alert messages can be simple; often, however, it is not simple and, due to interaction between systems, is subject to errors. It is felt that algorithms will gradually develop in pace with the development of software techniques. In any case, the algorithms for processing alert information must be conceived and developed by engineers intimately familiar with the systems involved. The best results will be obtained when the operating systems, fault monitoring system and alerting system are developed together. This does not preclude off-the-shelf systems for some of the more simple applications; however, the more sophisticated airliner with the most complete and capable alerting systems will need customized logic with sensors, fault monitoring and other digital systems designed with optimum alert processing in mind.

As digital technology continues to evolve, new computer techniques could be used to generate an alert from a set of conditional stimuli, none of which explicitly relates to the alerting situation (Ref. 9). Current technology can find rapid solutions involving many fixed and variable parameters. An example of such an approach would be for an ABORT TAKEOFF alert. Assume that the takeoff should be aborted if the engines don't attain/sustain a calculated thrust level, or failures occur in certain subsystems, or a tire is blown, etc.. Calculation of the thrust level required for takeoff involves knowledge of altitude, temperature, length of runway, obstructions, wind direction, wind velocity and aircraft weight. As the aircraft proceeds down the runway the go/no-go decision could also be influenced by the actual airspeed achieved and runway remaining in addition to the factors previously considered. To design an ABORT TAKEOFF alert, all this data (and probably much more when the design details are explored) must be made available; moreover, calculations must be continually made to determine the potential for success. At the same time, calculations for a one-engine out case should also be performed in the event

of an engine failure. Most of the data required for such automation is already available in the flight management, engine management and air data systems. Runway distance-to-go counted down by a nosewheel odometer, blown tire sensors and the capability to detect asymmetric flaps/slats, etc., are also already available on some aircraft. Although the complexity and the attendant reliability of integrating the required inputs needs to be considered in a practical design, it is a relatively easy task for a digital computer to continuously monitor the takeoff and make abort decisions quickly.

8.1.2 MEMORY SIZING

Memory size may not be an important factor in the cost, weight or volume of future alerting systems. Eight thousand 16-bit words of memory will suffice for the austere system whereas 64K words should be more than enough for the largest system, taking into consideration that most of the operational and sensor data is available from other subsystems. For comparison, an L1011 Flight Management System utilizes an 8K memory to acccomplish the navigation and performance management functions. A typical memory allocation budget for each of these two applications would be as follows:

	Austere	Maximum
Messages	1.6K	4.8K
Instructions	1.0	16.0
Parameters	.5	4.0
Scratch Pad	.5	1.0
Overhead	1.0	16.0
Growth	3.4	22.2
Total	8K	64K

Memory size, even for the maximum system, will not contribute greatly to the hardware weight and cost when compared with other factors associated with the development of digital systems. The major costs are in the software.

8.1.3 ARCHITECTURE

For the austere system, the hardware could be quite simple; inputs could be discretes from external switches or sensors such as flaps down, flaps half down, low voltage, low hydraulic pressure, etc. These inputs could usually be the same signals which operate the fault monitoring lights of present-day aircraft. Each could be input to the alerting computer on separate wires, and continuously scanned to set flags in a status section of the operational program. An executive routine could bring these status bits into the Random Access Memory (RAM) scratch pad memory one byte at a time for processing and appropriate action; the instruction program could address other status bytes into RAM as required for the logic sequence. For austere systems outputs could be sent via power switching transistors to an annunciator panel for lighting the appropriate message. For more sophisticated aircraft where the display is a CRT, the alert messages would be output to the display's signal generator in the appropriate sequence.

For the sophisticated system most of the input data could be taken from a digital data bus with only a small amount of discrete or analog data coming in on separate wires. All inputs could be paralleled to separate computers each of which would continually cross check the other(s).

The software could be organized to include an input scanning function with RAM storage, a logic instruction set, and self-test, control and output generating functions.

The details concerning hardware and software architecture are beyond the scope of this study. However, it is envisioned that hardware could be made the same for most types of aircraft; the software would step up in complexity as the system acquired additional sophistication. If a decision-making capability impacting flight safety were also to be introduced into the logic, the system reliability requirements would probably be increased considerably, thus drastically altering both the hardware and software architecture. For the

most sophisticated systems which could automatically reconfigure aircraft systems during emergencies, the computers would probably be triple or quadruply redundant with both self test and majority voting incorporated with an appropriate level of redundancy extended also to the display generators and displays.

8.2 PRIORITIZATION

As determined in earlier phases of this study, prioritization of alerts is desirable because the amount of information presented to the crew can be reduced considerably, and the most important problems presented first. Such logic can be implemented in the digital hardware; the problem is mainly in devising the software. Software design requires a thorough knowledge of the systems involved in a particular aircraft, as well as a clear understanding of airline procedures and pilot preferences and operating habits. A set of logic devised for one airline may not be acceptable for use with another airline. As with present systems, the aircraft manufacturer will devise the logic in consultation with the airlines, then make minor specific changes as desired by the various individual customers. As mentioned previously, the logic must be carefully analyzed to consider all foreseeable failure modes and sequences, then thoroughly tested to verify that important alerts are not masked or inhibited in previously unforeseen circumstances.

8.3 SENSOR DATA

Most of the sensors that would be required for a fault monitoring system can already be found on today's aircraft. However, additional sensors will probably be necessary to resolve ambiguities in the more capable systems. For example, it might be desirable to sense the extension of each slat element on a wing separately.

New sensors may also be needed to mechanize newly-identified alerts such as navigation error, windshear, tire and wheel faults, impending collision and takeoff abort. An alert for navigation error could be derived from existing

sensors but may require new algorithms in the navigation computer to detect deviation from desired flight path or proximity to terrain. A windshear alert would probably not require new sensors but would utilize new algorithms in the flight management system. Sensors for low tire pressure do exist but others are needed for wheel vibration. Collison avoidance sensors are now being explored. It is projected that a useable collision avoidance sensor and standardized maneuver algorithms will be available within the next five years. An alert for takeoff abort would require a runway position sensor (available), and a comprehensive interface with the aircraft, as well as a powerful processing capability and complex set of algorithms.

In summary, except for collision avoidance, development of an alerting system capable of flight status monitoring is not dependent upon new sensor technology.

8.4 CONTROLS AND DISPLAYS

The technology is currently available to implement the control and display functions of a flight monitor system. For the near term, some aircraft can afford the space, weight and cost of CRTs, whereas other aircraft might be constrained because of these factors. However, as flat panel display technology advances, the availability and cost of these displays will come within reach of the smaller aircraft. For the next generation aircraft (beyond the Boeing 757/767) display technology will not constrain the alerting system design; displays will be available at reasonable cost to display any format, in any color, and in any time sequence. Of course, cockpit panel space will always be at a premium, but the use of multipurpose displays with programmable controls for other display requirements will release sufficient panel space for alerting system requirements.

The controls pertaining exclusively to the alerting and warning system are not extensive; however, the controls associated with the emergency procedures, envisioned as being integrated into the system, could be extensive. These latter controls might be the same controls normally utilized for operating the

various aircraft systems. For this reason, they must be closely integrated with other system controls and associated logic. The implementation of controls therefore must be approached from an integrated system design point-of-view.

The use of voice alerts and messages is described in the Guidelines (Ref. 5). The hardware for this purpose is well along in development and should be able to provide the desired capability at a reasonable cost - near term for large aircraft and far term for the smaller aircraft.

Although the hardware doesn't pose a major problem, the design of messages, formats, logic, algorithms and software, as usual, will require the major effort. Software will vary in complexity from very simple for the austere airplane to quite complex for the other aircraft which may require the capability of extensive automatic emergency procedures and require considerable system redundancy.

8.5 INTERFACING

Eventually, even the most austere alerting system will be driven by a digital computer, thus the interfacing problem will be that of inputs to a digital computer. The more capable and advanced systems will have digital bus systems on which all sensor data will be multiplexed and available for all computational functions, including crew alerting. Interfacing in these cases will primarily involve software. In interim systems, which do not utilize general purpose data buses, the interfacing will be best handled by dedicated analog-to-digital converters sampling the sensor outputs at some medium rate, e.g., 30 samples per second. These A-D converters can be in an alerting computer or, in the larger aircraft, the converters may be remote to take advantage of the multiplexing to reduce wire weight. In any case the interface implementation will not be a unique problem; there will be many other avionic functions requiring the same type of interfacing.

9.0 RECOMMENDED FUTURE DIRECTIONS

This phase of the study has established the feasibility of the concept of expanding the functions of the alerting system to perform as a flight status monitor. Since the functional requirements to provide flight status monitoring significantly add to the requirements of the alerting system, it is necessary to take a systems approach to defining the new concept of a Flight Status Monitor.

9.1 REFINE EXPANDED ALERTING SYSTEM CONCEPTS

The first requirement is to expand the point of view from the concept of displaying alerts to a flight crew to a concept of providing crew alerting to both equipment malfunctions and abnormal operational conditions. As noted in the study, the expansion of the alerting system to perform a flight status monitor function would require additional sensing, computing and processing, interfacing, and controlling and displaying. These new functional requirements must be integrated to form the design concept for a Flight Status Monitor.

9.2 DEMONSTRATE FLIGHT STATUS MONITOR CONCEPT

The functional design concept for a Flight Status Monitor must be demonstrated to be feasible for implementation into hardware for flight deck applications. To accomplish this task it is recommended that a conceptual design be installed in a laboratory mock-up or a flight simulator for demonstration. The design need not be a full-up system, but sufficient to permit an evaluation of the concept and to support a decision to proceed to the next phase of development.

9.3 IMPLEMENTATION INTO HARDWARE

Following demonstration of feasiblity, it is recommended that a flightworthy system be fabricated for evaluation in an operational environment. The system should be sufficiently engineered to permit operation in a flight deck, but

not so integrated with other systems on the flight deck that removal following evaluation is prohibitive. This task requires that flight quality components be utilized in the design and that all interfaces between the system and the host vehicle be provided.

9.4 EVALUATION OF THE CONCEPT

It is recommended that the concept system be evaluated in the environment in which the system would be utilized. However, due to the impact of certification requirements and/or high cost of an evaluation on the flight deck of an aircraft, it is recommended that the evaluation of the flight status monitor be conducted in vehicles such as the National Aeronautics and Space Administration (NASA) Terminal Configured Vehicle (TCV) or other flight test vehicle. The system should be evaluated sufficiently to permit the establishment of minimum operating standards for the equipment and basic operating procedures for the use of the equipment.

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APPENDIX A

Accident/Incident Survey
Data Collection Form

SPACES REQUIRED	
001-003	ACCIDENT CODE NUMBER { Boeing 100 to 399; Douglas 400 to 699; Lockheed 700 & on }
004-009	DATE
010-017	AIRCRAFT TYPE (DC-8-50, 707-351, ETC.)
018-033	AIRLINE AIR CARRIER
034-045	LOCATION
046-057	POINT OF DEPARTURE (Last Aircraft Takeoff)
058-069	DESTINATION (LAST STOP)
070-073	FLIGHT DURATION (HOURS & MINUTES)
074-	FLIGHT PHASE – 1-Takeoff, 2-Initial Climb, 3-Climb, 4-Cruise, 5-Descent, 6-Initial Approach 7-Final Approach, 8-Landing, 9-Taxi (In or Out)
075-078	TIME OF DAY – Local Standard Time
079-	LIGHT CONDITIONS – 1-Day, 2-Night, 3-Dawn or Dusk
080-	AIRCRAFT DAMAGE – 1-Destroyed, 2-Substantial, 3-Minor, 4-None
081-	INJURIES – 1-Fatal, 2-Serious, 3-Minor, 4-None
082-	NUMBER OF COCKPIT CREW
083-	NUMBER OF OTHER PERSONS IN COCKPIT 9 NO OTHER PERSON
084-085	NUMBER FLIGHT HOURS IN LAST 24 HRS (CAPTAIN) (Add "9" in 084 For Estimate)
086-	PILOT AT CONTROLS – 1-Captain, 2-First Officer, 3-Shared (Switched), 0-Unknown
087-	WEATHER CONDITIONS – 1-IMC, 2-VMC, 0-Unknown
088-092	RUNWAY VISUAL RANGE – In Feet (0 in 088 if unkn) (9 in 088 in unlimited)
093-097	CEILING (WHEN PROBLEM OCCURRED) – In Feet (Add "9" in 093 For Unlimited) (0 in 093 if Unknown)
098-100	VISIBILITY RESTRICTIONS – Any Three 1-Fog, 2-Rain, 3-Dust, 4-Snow, 5-Haze, 6-Clouds

101- FLIGHT RULES - 1-IFR, 2-VFR 1-IFR

102- TYPE INSTRUMENT APPROACH - 1-ILS, 2-DME, 3-Other

103-107 ALTITUDE - When Occurence Initiated (1 = Sea Level in 107)

108- WAS AUTOPILOT ENGAGED? 1-Yes, 2-No, 0-Unknown

109- WAS AUTOTHROTTLE ENGAGED? 1-Yes, 2-No, 0-Unknown

110- WERE ANY CREW ALERTING DEVICES ACTIVATED AT TIME OF OCCURRENCE?
1-Yes, 2-Likely, 3-No, 0-Unknown

111-112 HOW MANY DEVICES WERE ACTIVATED? 99 = None

113-115 WHAT TYPES OF ALERTING DEVICES WERE ACTIVE AT TIME OF ACCIDENT?
(More Than One?) 1-Aural, 2-Visual, 3-Tactical, 4-None

WHAT SYSTEM FAILURES OCCURED?

1-Reported & Annunciated
2-Probable & Annunciated
3-Reported & Not Annunciated
0-Unknown

116- HYDRAULIC

117- FUEL

118- ELECTRICAL

119- ECS

120- AVIONICS

121- ICE & RAIN

122- FIRE

123- LANDING GEAR AND BRAKES

124- FLIGHT CONTROLS

125- ENGINES

126- GROUND PROXIMITY SYSTEM

127 OTHER

128 NONE

129	☐ WERE ANY ALERTS INDICATED IN SPACES 116-128 FALSE ALARMS? 1-Yes, 2-No, 0-Unknown Uncoded Statement - Describe Specific False Alarm ____ ____ ____ ____
130-210	80 Spaces Reserved For Coding Data in Table I, Listing of Alerting Devices That Should Have Been Activated For Each Failure Listed in Spaces 116-128.
211-	☐ WAS THE CORRECTIVE ACTION TAKEN APPROPRIATE FOR THE MALFUNCTION INDICATED IN SPACES 116-128? 1-Yes, 2-No, 3-Probable, 0-Unknown
212-	☐ WAS THE CREW PROVIDED WITH AN INDICATION OF THE CAUSAL FACTORS? 1-Yes, 2-No, 3-Probable, 0-Unknown
213-217	☐☐☐☐☐ IF "NO" IN SPACE 212, WHAT ADDITIONAL INFORMATION/ALERTS SHOULD HAVE BEEN PROVIDED? (5 SPACES RESERVED FOR CODING) PLACE "1" IN SPACE 213 IF TEXT IS PROVIDED. Noncoded Text - Describe Additional Information. ________________________________ ________________________________ ________________________________ ________________________________
218	☐ WHO PERFORMED THE CORRECTIVE ACTION FOR FAILURES LISTED IN SPACES 116-128? 1-Pilot Flying (on Controls) 2-Pilot Not Flying 3-Flight Engineer (2nd Officer) 0-Unknown/Not Reported
219	☐ HOW MANY CAUSAL FACTORS ARE GIVEN FOR THIS ACCIDENT?

CAUSAL FACTORS

Five Causes Can be Listed - 6 Spaces for Each List in Estimated Order of Contribution to the Accident.

FIRST SPACE IN EACH
- 1-Primary Cause (Can be More Than 1)
- 2-Contributing Cause

SECOND SPACE IN EACH
- 1-Cause Established by Investigation Agency - Official Cause
- 2-Cause Detemined From Available Data - Judgement

THIRD SPACE IN EACH MAJOR CAUSE
- 1-Cockpit Crew
- 2-Weather
- 3-Mechanical (Airplane)
- 4-Operational
- 5-Other
- 0-Unkn or awaiting report

LAST 3 SPACES IN EACH
Determine Detail Factor From Following Tabulations

220-225 ☐☐☐☐☐☐

226-231 ☐☐☐☐☐☐

232-237 ☐☐☐☐☐☐

238-243 ☐☐☐☐☐☐

244-249 ☐☐☐☐☐☐

SOURCE OF DATA

IDENTIFY ONE OR MORE
- 1-Primary Source
- 2-Supplemental Data

250- ☐ NTSB/CAB

251- ☐ FOREIGN GOVERNMENT REPORT

252- ☐ ICAD

253- ☐ IN-HOUSE DATA

254- ☐ ASRS

COCKPIT CREW FACTORS

Judgement

001 Misjudged speed, distance, altitude, clearance, etc.

002 Improper application of controls, brakes, flaps, etc.

003 Attempted operation with known deficiencies

004 Flight into known bad weather, in turbulence

005 Took too long to initiate proper action

006 Selected wrong action/took no action when one was required

007 Selected wrong control or put control in wrong position

Approval Procedures Not Followed

011 Failed to follow approved procedures, directives, instructions, etc.

012 Failed to use proper emergency procedures

013 Mismanagement of fuel

014 Failed to extend gear/retracted gear too soon

015 Operated aircraft outside of specs on standard configuration

Training/Experience/Supervision

021 Inadequate supervision by pilot in command

022 Inadequate training or experience

023 Flight manual - deficiency/error/ambiguous

Medical/Incapacitation/Physical Impairment

031 Hypoxia

032 Alochol

033 Physical impairment (e.g., heart attack)

034 Mental impairment (e.g., unconsciousness)

035 Sense impairment (e.g. sight, hearing)

Communications - Failure of Informative Transfer

041 Instruction (person to person) - misunderstood/ambiguous/ not received

042 Environment - too noisy/depressurization/disturbing

043 Instructions ignored or not heard

044 Language difficulty

045 Equipment information - misinterpreted (assume output correct)

Planning - Improper/Faulty/Inadequate, etc.

051 Improper pre-flight planning

052 Navigational error

053 Fuel mismanagement

054 Weight and balance error

Visual Impairment/Special Disorientations

061 Failed to see or avoid other aircraft or object

062 Light too bright/too dim/glared/reflections

063 Line of sight obstructed

064 Color coding inadequate or misunderstood

065 Shape coding inadequate or misunderstood

066 Visual signal - ignored or unseen

067 Smoke, haze, visibility impairment

Workload - Too High/Too Low

071 Extra task load caused errors or forgetfulness

072 Complacency errors caused by too little task requirements

073 Confusion caused by unclear task requirements

Distraction/Disturbed Mental State/Recklessness/Irresponsibility

081 Attention diverted from required task

082 Distraction from extra persons in cockpit

083 Illusions - false or real

084 Alcohol or drug induced

085 Distractions from smoke/fumes/odor

086 Distractions from temperature extremes

087 Abnormal behavior

Miscellaneous

091

092

WEATHER CAUSAL FACTORS

Select the weather data that describes the causal factors of the accident/incident

101 Fog

102 Rain/moisture

103 Snow

104 Hail/sleet/freezing rain

105 Wind

106 Restricted visibility (fog, dust, haze, etc.)

107 Thunderstorm/tornado

MECHANICAL CAUSAL FACTORS

Indicate which system(s) problems were considered causal factors

201 Corrosion, embrittlement, fatigue

202 System operated spontaneously and unexpectedly (not selected or wanted)

203 System selected by did not operate properly

204 Fluid loss or lack of
205 False warning indicated
206 No warning indication
207 Engine - foreign object damage
208 Engine - flame out or case penetration
209 Engine - tear away
210 Engine - partial or complete loss of thrust other than 7, 8, or 9
211 Fire/flame/smoke/explosion
212 Cabin depressurization
213 Rapid release of stored energy (O_2 bottles, accumulators, not tires)
214 Tire failure/wheel failure
215 Air conditioning
216 Auto flight
217 Communication
218 Electrical power
219 Fire protection
220 Flight control
221 Fuel and fuel controls
222 Hydraulic system
223 Ice and rain protection
224 Indicating/reporting system
225 Landing gear
226 Light
227 Navigation
228 Oxygen
229 Pneumatic/environmental control
230 Water/waste
231 Airborne aux power
232 Structure
233 Doors
234 Fuselage
235 Nacelles and pylons
236 Stabilizers
237 Windows
238 Wings

239 Power plant (cowling, electrical harness ducts, etc.)

240 Ignition and engine starting

241 Bleed air

242 Engine controls

243 Engine oil

244 Engine exhaust

OPERATIONAL CAUSAL FACTORS

Phase of flight related

301 At terminal - static
302 Taxi out
303 Taxi in to terminal

Takeoff

311 Tail smoke/over rotation
312 Run off runway
313 Engine related
314 Aborted takeoff
315 Tire failure
316 Wheel and brake

Climb

321 Fuel dump

Cruise

331 Oxygen mask deployment problem
332 Pressure loss in cabin
333 Engine thrust loss

Descent

341 Emergency descent

Approach

351 Landing aids failure

352 Asymmetric controls

Landing and roll out

361 Landed short

362 Ran off runway

363 Overweight landing

364 Landed long - more than 500' from threshold

365 Gear collapsed or was not down and locked

366 Tire or wheel damage

367 Hard landing

368 Ditching

OTHER/NON-FLIGHT PHASE RELATED

471 Evasive action to avoid collision

472 Any other abrupt maneuver

473 Collision (aircraft/bird/other object)

474 Uncontrolled attitude/altitude deviations

475 Communication (ATC, company, etc.)

APPENDIX B

Aircraft Alerting Systems Standardization Study

Cockpit Observation Form

AIRCRAFT ALERTING SYSTEMS STANDARDIZATION STUDY COCKPIT OBSERVATION FORM	NAME OF AIR CARRIER	FLT NO

NAME OF PILOT-IN-COMMAND	NAME OF SECOND-IN-COMMAND	NAME OF FLIGHT ENGINEER

DEPARTURE			DESTINATION	ESTIMATED TIME EN ROUTE
TIME	DATE	FROM		

ROUTE FLOWN	TYPE AIRCRAFT	CREW BASE (CITY & STATE)

OBSERVER CHECKLIST

OBS	REC	ITEM
		PRELIGHT
X		WEATHER ANALYSIS
X		FLIGHT PLANNING
X		CREW BRIEFING
X		COCKPIT DESIGN
	X	DISPATCH ITEMS ( ) NUMBER
X		ALERTING SYSTEM CHECKOUT
	X	ALERTING SYSTEM DISCREPANCIES
X	X	NUMBER OF VOICE TRANSMISSIONS
X		USE OF CHECKLISTS
		DEPARTURE
X		STARTING PROCEDURE
X		USE OF CHECKLISTS
X	X	ALERTING SYSTEM OPERATION/USAGE
X		RUN-UP
	X	INSTRUCTIONS ON EMERGENCY PROCEDURES ☐ YES ☐ NO
X		CLEARANCE
	X	V_1, V_R, AND V_2 CALLOUTS ☐ YES ☐ NO
	X	TAKEOFF ☐ IFR ☐ VFR AUTOPILOT ☐ YES ☐ NO
X		CLIMBOUT
	X	AUTOPILOT ON ( ) ALTITUDE
X		CREW DUTIES
X	X	NUMBER OF VOICE TRANSMISSIONS
	X	CREW ACTIVITY ☐ HIGH ☐ MED ☐ LOW
		EN ROUTE
X		LEVEL OFF
X		USE OF CHECKLISTS
X	X	ALTITUDE ALERTING SYSTEM ( ) ALERTS
X		USE OF NAVAID FACILITIES/RADIO TUNING
X		NAVIGATION PROCEDURES
X		CREW DUTIES
	X	CREW ACTIVITY ☐ HIGH ☐ MED ☐ LOW
X	X	ALERTING SYSTEM OPERATIONS/ALERTS
X	X	NUMBER OF VOICE TRANSMISSIONS

OBS	REC	ITEM
		APPROACH AND LANDING
X		AIRCRAFT CONFIGURATION CHANGES
X		AIRSPEED/POWER CHANGES
X		USE OF CHECKLISTS
X		CREW DUTIES
X		APPROACH CLEARANCE
	X	TYPE OF APPROACH ☐ IFR ☐ VFR COUPLED ☐ YES ☐ NO
X	X	NUMBER OF VOICE TRANSMISSIONS
	X	CREW ACTIVITY ☐ HIGH ☐ MED ☐ LOW
X	X	ALERTING SYSTEM OPERATION/ALERTS
X		CREW DUTIES
	X	AUTOLAND ☐ YES ☐ NO
		GENERAL
	X	HANDLING OF EMERGENCIES (NARRATIVE)
X		AIRCRAFT DISCREPANCIES HOW HANDLED
X		A/C LIMITATIONS
X		USE OF CHECKLISTS
X		COORDINATION WITH ATC
	X	QUIET DARK COCKPIT ☐ YES ☐ NO

ALERT ANNUNCIATED	ALTITUDE OF OCCURRENCE	FLIGHT PHASE

DESCRIBE SITUATION AND CREW RESPONSE
CORRECTIVE ACTION TAKEN
POSTFLIGHT NARRATIVE
COMMENTS/NOTES